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FINAL REPORT

of the

USAF Academy Risk Analysis Study Team

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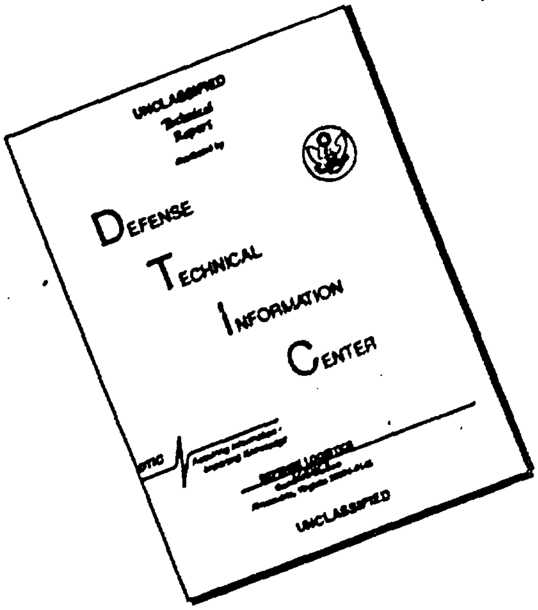

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INTRODUCTION

Despite significant study and corrective effort over a period of two decades, the defense system acquisition process in the U S continues to be plagued with major cost overruns, schedule slippages, and hardware performance deficiencies. The paradox is that most people in government, the military services, and industry who work in this area honestly desire that this situation be otherwise--and they share a growing personal frustration that improved results have not been produced in spite of redoubling of their individual efforts. By implication, there is something very fundamentally wrong or lacking in our policies and/or practices which has escaped identification and attention.

At the outset of his tenure, the present Deputy Secretary of Defense focused on cost growth in systems acquisition as a problem which should be given priority consideration. Optimism in program cost estimates, cost growth via excessive development and production changes, failure to identify major risk areas, and excessive dependence on paper analyses were identified as the principal causes. In his memoranda of 31 July 1969 and 28 May 1970, the Deputy Secretary directed the Service Secretaries to identify areas of high technical risk, to accomplish "formal risk analysis," and to expand program management practices to include explicit consideration of risk assessment, risk reduction, and risk avoidance.

The application of risk analysis as defined in this report appears to have great potential at all levels of the acquisition process--from the program manager to the OSD policy guidance staffs. However, in its present state of evolution, risk analysis is not a science--or even an art. Indeed, in the context of the systems acquisition process, it is

Chapter V addresses, in a normative fashion, the subject of how to perform a risk analysis, what the outputs should be, and some of the uses and benefits.

Chapter VI presents the conclusions and recommendations of this study team.

The authors are indebted to more people in the academic community, DOD, and industry than we can acknowledge individually. Without their cooperation, guidance, and experience--together with generous contributions in time, travel, and creative suggestions--the study team could not have penetrated very far into the intangible subject of risk analysis. Of utmost importance was the generous support of Edward Ball and James Grodsky, Research and Development Policy, ODDR&E, and the management research grant provided by the Aeronautical Systems Division, AF Systems Command. Particular recognition must also be made of the spontaneous responses by Army and Navy Department personnel at every level which, together with Air Force contributions, gave the researchers a balanced, tri-Service perspective concerning on-going programs and risk analysis activities. Finally, it is important to recognize that this report represents the views, conclusions, and recommendations of the study team and has not been officially approved by any DOD staff or line agency.

EXECUTIVE SUMMARY

Introduction

This study investigates a method of reducing cost growth and improving quality in the weapon system acquisition process. Other recent analyses have focused on identifying and correcting major deficiencies in current policy guidance and management procedures. This study, by an interdisciplinary team of Air Force Academy faculty members, takes a more speculative approach by investigating a new management process, "formal risk analysis."

Risk analysis is presently neither an art nor a science. As a result, the informal, fragmented efforts attempted in the past have not been effective in solving the overall problem which is so complex, so ill defined and nebulous that arriving at acceptable definitions, discovering the major sources of risk, developing working models for effective analysis and evaluation, and distilling pertinent information and techniques into meaningful guidelines are themselves problems of staggering magnitude.

Different organizations use the terminology of risk analysis in different ways; therefore, it is necessary to clarify risk analysis as used in this report. Risk is the probability that a project will not be completed within specified time, cost and performance constraints by following a specified course of action. Risk assessment is an estimate of the risk associated with a particular course of action. Risk management is the generation of alternative courses of action for reducing risk. Risk analysis is the larger process of combining risk assessment and risk management in order to examine factors affecting the risk of acquiring a system. It is the purpose herein to identify what a risk analysis is, how it can be accomplished, who should accomplish it and where it fits in the management structure for weapons systems acquisition.

Risk and Uncertainty

To determine the risk associated with the acquisition of a weapon system, it is necessary to do the following: (1) Establish the dominant uncertainties which are present; (2) Select a promising course of action based on these uncertainties; (3) Assess the risk of this course of action; (4) Generate alternatives; (5) Assess their risks, and (6) Iterate to a point of diminishing returns. This is a risk analysis, and it can be used as one input in the selection of a preferred course of action.

The study team found that uncertainty in the weapons system acquisition process fell naturally into four relatively clear-cut categories: TARGET, TECHNICAL, INTERNAL PROGRAM and PROCESS. Target uncertainty involves a lack of knowledge concerning what end items are

desired and what criteria should be used to evaluate them. Technical uncertainty involves solving technical problems. Internal Program uncertainty involves uncertainty about how a program should be planned and managed. Process uncertainty involves the program's interaction with the external environment and revolves around uncertainty over the availability of the resources required to complete a program and the criteria and thresholds employed in program approval. Experience has shown that this categorizing sharpens analysis of how uncertainty acts to generate risk.

One result of this study is the discovery that many causes of cost growth are introduced early in a program before the Program Manager assumes responsibility. Thus an important task for the study team has been to identify and categorize the major uncertainties inherent in the program and outside the jurisdiction of the Program Manager.

Risk Management

Risk management involves the selection of a set of alternative courses of action to reduce or avoid risk. Initial alternatives are selected based on the categories of uncertainty that dominate the program and differ according to the type of uncertainty. For example, if target uncertainty is predominant: (1) threat studies need to be continued through the development period; (2) parallel development of competing systems is not appropriate; (3) performance requirements need to be stated in terms of intervals rather than points; (4) a source for tradeoff decisions between the Program Manager and OSD authorities is desirable; (5) a restatement of performance requirements is needed after development source selection; and (6) operational prototyping should be considered.

If technical uncertainty is paramount: (1) model testing and development, production, or operational prototyping needs to be considered in lieu of paper analyses; (2) parallel development by more than one approach is indicated for quantum technology jumps; and (3) subcontractors with a proprietary state-of-the-art advantage should be made available to all prospective contractors.

Internal program uncertainty requires: (1) a maximum of flexibility in program design; (2) increased communication among Program Managers; (3) high visibility for military Program Managers to improve the career aspects of their jobs; and (4) possible production prototyping.

Process uncertainty encompases a multitude of unknowns and indicates: (1) the need for program approval to be clearly defined; (2) that tradeoff authority that is beyond the Program Manager be rapidly available to him; and (3) the Program Manager should conduct a continuing sensitivity analysis of possible impacts due to unexpected funding changes.

Risk Assessment

A risk assessment is a comprehensive, carefully structured approach for estimating the risk profile of a particular alternative course of action. A risk assessment of each of several alternative courses of action is then part of a risk analysis.

A quality risk assessment can be accomplished only by a group of trained analysts in mathematics, probability, statistics, operations research, and computer science - aided by cost analysts, production, design, and engineering people, and experts in various technical disciplines.

The quantitative disciplines involved in risk assessment are group assessment techniques, subjective probability, trend extrapolation, cost estimating, and network analysis. The first four can be used to produce terminal results or to provide inputs to the more powerful technique of network analysis. The outputs which they produce, though useful, do not supply the kind of information necessary for a quantitative risk assessment of the type required. The technique which offers the most promise in quantitative risk assessment is a versatile, simulated network approach using group assessment techniques, subjective probability, technological forecasting, cost estimating, and others as sources of input.

Risk Analysis

The techniques for conducting a risk analysis exist; however, a single procedure should not be established since the best procedures will differ with various projects. On the other hand, the outputs of an analysis can be fairly well specified.

1. A general description of the dominant uncertainties (target, technical, internal program, or process) which directed the selection of the original course of action.

2. Identification of alternate courses of action (such as hardware proofing, parallel development, etc.) to resolve the major uncertainties.

3. A detailed discussion of the potential problems in each major program element for each course of action considered.

4. Individual and joint risk profiles of time and cost for each alternative course of action. The inherent assumption is that the specific desired performance is obtained by following the course of action.

5. An analysis of how sensitive the risk profiles are to change in the inputs.

6. Tradeoffs, as recommended by the Program Manager, for maintaining the overall program within specified cost, time, and performance thresholds.

7. Comparison with previous risk analyses of the same project.

8. A comparison of the candidate management courses of action and a recommendation of a preferred course of action on the basis of risk considerations alone.

9. A discussion of the major assumptions and an explanation of the disparity when the results are different from those expected.

The concept that a risk analysis requires an iterative interaction between the manager and the assessors, coupled with the fact that only the contractor has ready access to the vast amount of necessary data, dictates that the analysis must be performed in the military or contractor Program Office.

The contractor should continually assess the total program risks. The prime benefactor of a risk analysis, the Program Manager, can then request an analysis of several alternative courses of action each time the assessment indicates the need for a tradeoff decision in a program element. Although a risk analysis would be but one input to such a decision, it could be an important one.

The results of a thorough risk analysis should be presented by the Program Manager each time the program is reviewed for a major decision by high level Service authority. Such an analysis ordinarily includes a comprehensive study of several alternative courses of action for consideration by the decision maker. For a DSARC or congressional review, the risk profiles for time and cost for the preferred course of action should be presented. These profiles provide immediate identification of the program risks fixed by the DCP thresholds and serve as useful inputs to adjustment of those thresholds. The reviewing authority cannot conduct a meaningful independent risk analysis. For further objectivity; however, he could request an independent evaluation of the Program Manager's analysis.

Conclusions and Recommendations

1. Conclusion:

ONE OF THE BASIC PROBLEMS IN ANY STUDY ON RISK IS THE LACK OF A GENERALLY ACCEPTED GROUP OF DEFINITIONS.

Recommendation:

ESTABLISH DOD DEFINITIONS OF THE BASIC TERMS AND CONCEPTS USED IN RISK ANALYSIS:

RISK: The probability that a planned event will not be attained within constraints (cost, schedule, performance) by following a specified course of action.

UNCERTAINTY: Incomplete knowledge.

RISK ASSESSMENT: A comprehensive and structured process for estimating the risk associated with a particular alternative course of action; also the product of such a process.

RISK MANAGEMENT: The generation of alternative courses of action for reducing risk.

RISK ANALYSIS: The process of combining the risk assessment with risk management in an iterative cycle; also the product of such a process.

2. Conclusion:

TECHNICAL UNCERTAINTY MAY BE ONLY A SMALL PART OF THE WEAPON SYSTEM ACQUISITION PROBLEM. SUCCESSFUL PROGRAM DIRECTION ALSO REQUIRES MANAGEMENT CONSIDERATION OF TARGET, INTERNAL PROGRAM, AND PROCESS UNCERTAINTIES.

Recommendation:

REQUIRE ANY "RISK ANALYSIS" TO INCLUDE CONSIDERATION OF TARGET, TECHNICAL, INTERNAL PROGRAM, AND PROCESS UNCERTAINTIES.

3. Conclusion:

IN THE AREA OF QUANTITATIVE RISK ASSESSMENT, AGGREGATION TECHNIQUES (SUCH AS NETWORK ANALYSIS) ARE FAR MORE ADVANCED THAN THE TECHNIQUES FOR OBTAINING INPUT DATA (SUCH AS SUBJECTIVE PROBABILITY AND TECHNOLOGICAL FORECASTING).

Recommendation:

FUNDING PRIORITY FOR IMPROVING METHODS FOR QUANTITATIVE RISK ASSESSMENT SHOULD BE GIVEN TO DEVELOPMENT OF INPUT TECHNIQUES.

4. Conclusion:

RISK ANALYSIS PRIMARILY BENEFITS THE PROGRAM MANAGER. NO AGENCY OUTSIDE THE MILITARY OR CONTRACTOR PROGRAM OFFICE CAN EFFECTIVELY PERFORM A RISK ANALYSIS OF THAT PROGRAM.

4. Recommendation:

- Direct each concept formulation contractor to perform a risk analysis.
- Direct each contractor in the source selection competition to perform a risk analysis and specifically include at least the uncertainties identified by the risk analysis performed during concept formulation.
- Require the Program Manager and the winning contractor to update the risk analysis after source selection and before contract award.
- Direct the contractor for each major on-going program to conduct a continuing assessment of the risk in the program.
- Require the Program Manager to present the results of a current risk analysis, to include alternative courses of action, each time the program is reviewed by higher service authority for a major tradeoff decision.
- Require the Program Manager to present the results of a risk assessment of his program, specifically the risk profiles for time and cost, each time the program is reviewed by the DSARC.
- Require an independent evaluation of the risk analysis or assessment each time the program status is presented to higher authority for a major tradeoff or milestone review.

5. Conclusion:

INITIAL COST AND SCHEDULE ESTIMATES FOR MAJOR PROGRAMS HAVE INVARIABLY BEEN OVER-OPTIMISTIC. THE RISK THAT COST AND SCHEDULE CONSTRAINTS WILL NOT BE MET CANNOT BE DETERMINED IF COST AND SCHEDULE ESTIMATES ARE GIVEN IN TERMS OF SINGLE POINTS RATHER THAN DISTRIBUTIONS.

Recommendation:

REPLACE THE POINT ESTIMATES OF COST AND SCHEDULE PRESENTLY USED WITH THE JOINT RISK PROFILE FOR COST AND SCHEDULE FROM THE RISK ANALYSIS DEVELOPED AT THE COMPLETION OF SOURCE SELECTION.

6. Conclusion:

TO OUR KNOWLEDGE NO MAJOR DOD PROGRAM HAS DEVELOPED OR USED A RISK ANALYSIS OF THE MAGNITUDE ENVISIONED IN THIS REPORT.

6. Recommendation:

INITIATE TEST CASES IMMEDIATELY. FORMAL RISK ASSESSMENT AND ANALYSES SHOULD BE USED THROUGHOUT THESE PILOT PROGRAMS TO DETERMINE THEIR FEASIBILITY AND UTILITY TO A DECISION MAKER.

7. Conclusion:

THERE IS NO "ONE BEST WAY" TO CONDUCT A RISK ANALYSIS.

Recommendation:

THE FOLLOWING LIST OF OUTPUTS FOR A RISK ANALYSIS IS RECOMMENDED. PILOT PROGRAMS SHOULD RECOMMEND THE MOST USEFUL OUTPUTS.

1. A general description of the types of uncertainties in the program.
2. A detailed discussion of the potential problems in each major program element (engine, etc.).
3. Identification of alternative management courses of action to resolve the major uncertainties.
4. Probability distributions of time and cost; risk profiles for each course of action.
5. A sensitivity analysis to determine the effect of input perturbations on the risk assessment output.
6. Tradeoff studies as directed by the Program Manager for maintaining the overall program within specified cost, time and performance thresholds.
7. Comparison with previous risk analyses to identify trends.
8. A comparison of the candidate courses of action and a reccommendation of a preferred strategy based on risk considerations alone.
9. A discussion of the major assumptions and an explanation of the disparity when the results are different from those expected.

8. Conclusion:

THE CONCEPTS OF RISK ANALYSIS ARE INADEQUATELY UNDERSTOOD. AN EDUCATION PROGRAM IS NEEDED TO INSTRUCT ANALYSTS AND MANAGERS IN THE PREPARATION AND USE OF A FORMAL RISK ANALYSIS.

8. Recommendation:

FOLLOWING A MEANINGFUL PILOT PROGRAM, DESIGN AND IMPLEMENT A RISK ANALYSIS EDUCATION PROGRAM WITH THE FOLLOWING MAJOR AREAS OF EMPHASIS:

Short orientation courses in risk analysis for high level officials who deal with uncertainties in program management and program approval.

Longer training courses to outline the details of risk assessment techniques for selected personnel who may be required to perform or evaluate such assessments in the government and industry Program Offices.

Introduction of Risk Analysis as a discrete subject in appropriate government management schools.

Assignment of specially talented military and civil service personnel to a non-profit corporation or priviate consulting firm with expertise in Risk Analysis.

CHAPTER I: THE RISK ANALYSIS PROBLEM

The Setting of the Problem

Cost overruns, schedule slippage and performance degradation in American weapons acquisition have reached intolerable proportions at all levels of American society and government. The prevailing attitude is one sharpened by the fact that the defense of the nation is involved, and the cost of weapons is going up as the ability to purchase is going down. There are also severe and competing social problems. Equally disturbing is the fact that no one seems able to put his finger squarely on what is wrong. Guesses range from outright fraud and conspiracy on the part of the "military-industrial" complex to "built-in inefficiences" of the most complex weapons acquisition process the world has ever seen.

This study is not the first "hard look" at the problem. Several note-worthy groups have produced a number of significant studies. At the same time, an impressive number of individuals have developed approaches and techniques for dealing with particular aspects of the situation. This study reflects the concern at the policy level. It is thus an attempt to look at the problem as a whole, to see as clearly as possible both the magnitude of the problem, and possible approaches to its solution.

The solution to the problem obviously depends on the diagnosis of its cause. If, for example, fraud is involved, firm and enforceable laws may be the answer; if inefficiency, better management. Unfortunately, the problem has defied simple diagnosis and hence simple solutions. Indeed, the fact that so much of the cost overruns and schedule slippages have more or less caught everyone by surprise indicates that the fault, in large part, rests with factors which were not anticipated when the

original estimates were made. This alone suggests that the solution lies in better anticipation, assessment and management of these factors, a process that is loosely called "Risk Analysis."

Study Genesis and Approach

This study was undertaken because of wide interest within DOD and industry in the requirement for "formal risk analysis" which the Deputy Secretary of Defense directed in his memoranda of 31 July 1969 and 28 May 1970 (1,2).* Additional motivation was provided by OSD policy guidance:

> All new programs will be kept in the conceptual development stages until the responsible Service Secretary and the OSD can be assured that the program is actually in the proper shape to proceed into full-scale development. (2, p. 3)

The objective of the research was to distill available expertise on risk analysis, to examine the benefits and utility of such an analysis, and to suggest possibilities for using risk analysis in the systems acquisition process. At the very least it was anticipated that the study would reveal what kind of an analysis might be acceptable to OSD.

The study team established contacts with management consultants and academicians, with program managers in the Services and industry, and with professional groups and DOD policy staffs. Through these contacts an extensive library was assembled on the subjects of risk, uncertainty, decision theory, and the defense systems acquisition process.

Status of the Art

Risk Analysis and cost analysis are sometimes thought to be comparable disciplines. But there are fundamental differences between the two.

*Numbers in parentheses refer to items in the Bibliography at the end of this volume.

Cost, of course, is an explicit parameter measured in familiar terms with fairly simple quantitative techniques for data manipulation. For example, derivation of total program cost--given those of its elements--is not a calculation of great difficulty.

Risk, on the other hand, is quantified in the less familiar terms of probability and the derivation of total program risk is a much more difficult process, although methods do exist. Like cost analysis risk analysis is best performed by specialists. The major problem common to both is the acquisition of valid input data.

In summary, it is unfortunately true that risk analysis--in the context of the weapon system acquisition process--does not enjoy the recognition and use as does, for example, cost analysis. Rather, it is at best an art in a relatively primitive state of development, albeit one with the gleam of considerable promise.

Areas of Application for Risk Analysis

Some classical studies of cost growth over the past two decades were accomplished by Peck and Scherer (3) and Marshall and Meckling (4). These showed the average USAF programs overran original cost estimates by a factor of 300% and experienced schedule slippage factors of 135%. Some graphic illustrations are:

			Average Unit Cost
Tactical Fighters:	F-100	(2240 produced):	$ 800,000
	F-105	(835 produced):	$ 4,000,000
	F-111A	(160 produced):	$ 8,500,000
Strategic Bombers:	B-47	(2040 produced):	$ 2,270,000
	B-52	(745 produced):	$ 7,200,000
	B-58	(115 produced):	$12,400,000
	B-1	(in development):	$30,000,000(estimated)

			Average Unit Cost
Military Transports:	C-47	(10500 produced):	$ 100,000
	C-124	(450 produced):	$ 1,600,000
	C-130	(338 produced):	$ 2,800,000
	C-141	(280 produced):	$ 8,500,000
	C-5A	(20 produced):	$30,000,000

Table 1
USAF Aircraft Cost and Quantity Trends

This table dramatically demonstrates two well-known trends: a rise in unit cost and a decrease in the quantity of aircraft produced. An unfortunate result of cost growth has been the necessary reduction in the number of weapons available for the defense of the nation.

Numerous studies of the causes of cost growth have recently been accomplished by competent teams in government and industry.* From a risk viewpoint, an amazing pattern of risk initiation, risk growth, and risk transfer emerges--especially during the early phases of the system life cycle. In general, programs are doomed to inevitable cost growth and schedule slippage prior to the establishment of a Program Manager (PM). There is ample evidence of inattention to risk in all phases of the acquisition cycle. There is a need for serious attention to the risks in programs in each of the following areas:

1. Concept Formulation. For more than two decades concept formulation studies have pressed for the last 10% in the state-of-the-art and the earliest possible operational availability for new weapon systems. Thus, from the outset, there has been high risk of exceeding cost and schedule thresholds.

2. Threat Evaluation. Those responsible for defining operational requirements are motivated to insure success in their functional area by

*See items 5 through 15 of the Chapter I Bibliography.

projecting maximum enemy capabilities rather than by using probabilistic estimates. This results in unrealistically high performance goals which increase risk and leave the PM little or no allowance for meaningful tradeoffs.

3. Initial Program Estimates. Probably the most significant single factor in apparent cost growth is the unrealistically low initial program cost estimate submitted to Congress. By this approach, which minimizes the chance of Congressional disapproval, planners transfer risk to the PM, and the program is in serious funding trouble from the start.

4. Source Selection. During source selection, contractors minimize their chance of losing the competition by submitting the most optimistic proposals regarding the unrealistically high performance and schedule goals. At the same time, they tailor their bid costs to the unrealistically low funding authorized by Congress. Unavoidably, the accumulation and growth of risk at this point is beyond the means of most Program Managers to correct.

5. High Technology Programs. Over the past 25 years, preoccupation with advanced technology has produced a generation of scientist-managers who have been trained, rewarded, and promoted on the basis of their ability to manage technical innovation. As these skilled professionals came into dominance, the practitioners of conservative, cost-conscious design declined in numbers and influence. Thus, the programs of the 1970's are subject to substantial risks because of a propensity for overdesign and excessive technology.

6. Engineering Management Systems. The pursuit of advanced technology and the advent of the scientist-manager has resulted in laissez-faire management discipline similar to that which promotes

technological breakthroughs in research laboratories. To insure minimum standards of management discipline, however, a vast array of government imposed management, control, and information systems has been imposed. These systems are expensive and time consuming--and may be counter-productive. They are an important source of risk and inefficiency in program management.

7. Anticipated Unknowns. The competitive urge to be the leader in producing and fielding advanced weapons often encourages unwarranted optimism regarding programmed milestones. Too often, preoccupation with schedules induces only partial completion of development tasks in order to reduce the chance of delaying commitments to full production. In this way substantial risks are developed and transferred to later phases of the acquisition cycle.

8. Unanticipated Unknowns. During the 1960's the defense acquisition process gravitated toward complete system specification based on paperwork planning and paperwork source selection. Military and contractor PM's have been deluded into thinking program problems have been identified. The result has been a further proliferation of hidden problems which grow and later in the program cycle result in breaches of cost, schedule, and performance goals.

The Semantics of Risk Analysis

Risk analysis is not an established science. Many of its terms are borrowed from other disciplines; so some of the key words will mean different things to different people. Accordingly, it is necessary to define the major terms.

"Risk" itself has decidely different non-technical and technical meanings. In the former usage for example, it means taking a chance or

exposure to adversity or danger.

For the purposes of this study, we have adopted a modified form of the AIA definition of risk (9, p. 75) as the probability of failure.

RISK: The probability that a planned event will <u>not</u> be attained within constraints (cost, schedule, performance) by following a specified course of action.

Risk is often confused with uncertainty; though linked, the two concepts are <u>not</u> the same.

UNCERTAINTY: Incomplete knowledge.

Risk assessment involves the process of risk estimation.

RISK ASSESSMENT: A comprehensive and structured process for estimating the risk associated with a particular alternative course of action; also the product of such a process.

Risk management is concerned with the generation of alternative courses of action to be assessed for risk. The purpose of the assessments is to provide the manager with a comparison of the risks involved.

RISK MANAGEMENT: The generation of alternative courses of action for reducing risk.

Risk analysis combines the functions of risk assessment and risk management.

RISK ANALYSIS: The process of combining the risk assessment with risk management in an iterative cycle; also the product of such a process.

The Structure of Risk Analysis

A risk analysis is a joint effort of an analyst-manager team. The manager is charged with the generation of alternative courses of action designed to develop the weapon system under consideration. The function of the analyst is to assess, through mathematical means, the risk involved in achieving the desired product as a function of the cost and time--and to indicate the subsystem developments which most affect the program risk. The manager is then motivated to modify the courses of action to reduce or avoid the risky developments. The risks associated with these courses of action are then assessed by the analyst. This assessment-modification iteration proceeds until the manager is satisfied that he need not optimize the alternatives further--at which time he selects a course of action to use in proceeding from where he is to program fruition. The procedure does not guarantee an optimum course of action, but serves to apprise the manager of the risk inherent in his selected strategy.

In order to accomplish a valid risk analysis, those who are accomplishing the assessment need access to planned development strategies. In the early part of a program, analysis is best done by either the Service staff or a contractor retained to study the development. When the Program Office has been established, the analysis is best performed by either the contractor or a staff assigned to the Program Manager. In those instances where the risk analysis or assessment is used as part of a presentation to higher level authority for a major tradeoff decision or milestone review, an independent objective evaluation of the analysis should be performed.

Scope of the Study

The major purposes of this study are to describe what should constitute a risk analysis, to indicate where, when, and how such a risk analysis should be used, and to establish why risk analysis as presented in this study can be an effective tool in reducing the excessive cost growth, schedule slippage, and performance problems which increasingly plague the weapon system acquisition process. Additionally, areas in which follow-up effort and research are required are identified.

The scope of the study is restricted in several ways. First, considerations of national priorities, military utility, and the political environment are excluded from risk analysis as it is recommended herein. Secondly, time constraints precluded detailed study of the role of contracting in program management and its effect on risk. We recognize, however, that meaningful risk management is possible only if the assessed risk is contractually recognized. This means that follow-on studies should include careful attention to contractually recognizing assessed risk in ways which will provide the flexibility in the contract instrument needed to motivate the contractor and permit desired tradeoffs.

Finally, this study is not intended to be a technical manual or procedual checklist for those who may have to actually perform a risk analysis. Rather, it is intended to provide the basis for management guidance and policy in implementing risk analysis.

CHAPTER II: RISK & UNCERTAINTY

General Considerations

Risk has previously been defined to be the probability that an event will not be completed within specified time, cost and performance constraints by following a specified course of action.

Uncertainty has been characterized as a state of incomplete knowledge. Thus risk and uncertainty are not synonymous. Their relationship is probably best illustrated through the example shown in Figure 1.

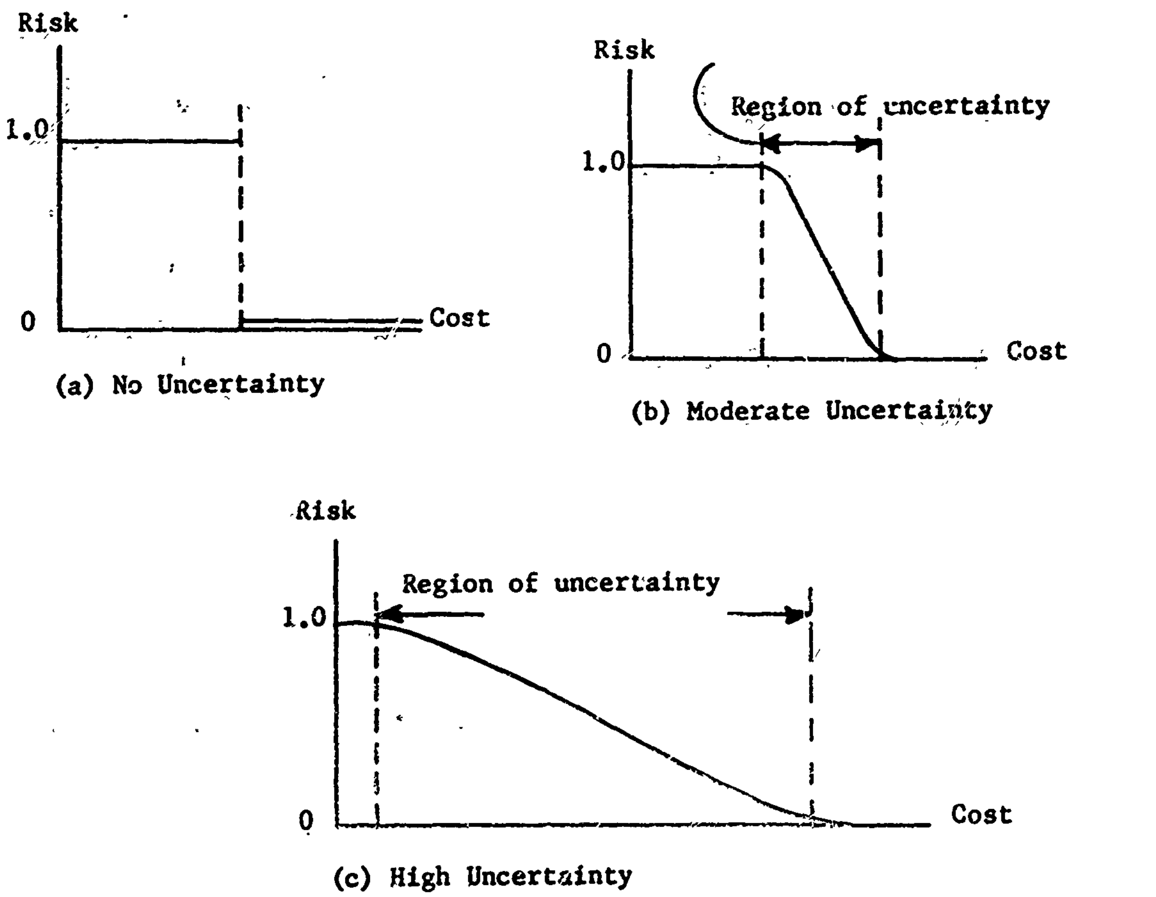

Figure 1.
Relationship Between Risk and Uncertainty

Consider first the development of a product which is so far within the state-of-the-art that the cost of development may be ascertained with certainty. (Figure 1a.) Then the risk associated with its development is either zero (if the cost constraint is greater than the actual cost) or one (if the cost constraint is less than the actual cost). Thus, where there is no uncertainty, it is known in advance whether or not a project can be completed within a specified cost constraint.

Now consider the development of a product in which there are uncertainties involved. Again, if the cost constraint is too stringent, the risk is one (the project is a certain failure); if it is sufficiently relaxed, the risk is zero (the project is a certain success). There is, however, a middle ground in which, for certain cost constraints, the risk is somewhere between zero and one; that is, there is some chance the project will be a success and some chance it will not. The more uncertainty there is in a project, the greater will be this middle ground in which only a probabilistic estimate of success may be made. (Figures 1b and 1c.)

As time goes on and as money is spent in a particular project more knowledge may be obtained and therefore the uncertainties may be reduced and the estimates of risk may improve. However, the risk of completing the project within the original cost constraint may either go down, remain the same, or go up. In other words, the additional knowledge obtained may show that the project was less expensive than originally thought, about the same, or more expensive. This same discussion could apply to time as well.

The initial thrust of this study was directed toward the analysis of "technical" risk and the technological uncertainty associated with it. It quickly became apparent, however, that "technical" uncertainty was only

the visible tip of the iceberg. Submerged beneath the surface and frequently having a far greater impact on program objectives and success in meeting them were a number of additional uncertainties, none of them purely "technical" in origin and not all of them internal to the program.

We have classified these uncertainties into four categories: TARGET, TECHNICAL, INTERNAL PROGRAM and PROCESS. There is some overlap among these categories, and the boundaries between them must, in some cases, be arbitrarily defined. It might be more accurate to describe them as components in a differentiated continuum of uncertainty rather than as discrete categories. Nevertheless, the essential differences between them are clear. It is the experience of the study team that viewing uncertainty in this way sharpens analysis of its impact on the weapons system acquisition process, leading to an enhanced understanding of the mechanism connecting uncertainty with risk.

Target Uncertainties

Description.--The term "target" is used in this report to refer to the desired physical and performance characteristics which a weapons system must have to satisfy a given need or requirement. Target also refers to the desired cost and schedule goals established for the development program. Target uncertainty is the uncertainty involved in reducing a need to cost, schedule, and performance goals.

Discussion.--Target uncertainties enter the weapons system acquisition process throughout its life cycle in a variety of ways. These can be generally summarized as follows:

- Uncertainty concerning the nature of the need or desired operational capability.

- o Uncertainty introduced through the formal process of generating requirements.
- o Uncertainty concerning the physical and performance characteristics which the system must possess if it is to satisfy the stated requirement.
- o Uncertainty of cost and schedule estimates.

The uncertainty of the need stems largely from the vagaries of international relations, the intent and capabilities of U.S. foreign policy, the nature and extent of enemy threats and consequent uncertainty concerning the nature of the expected operational environment. Even when the need is well defined and clearly understood, uncertainty can be introduced through the mechanics of converting the need into a stated requirement for hardware. This can begin with a poorly structured, undefined concept formulation phase and run throughout the life of the program. Once the need for a particular kind of weapon system is determined, it becomes necessary to configure it in accordance with clearcut physical specifications--established target criteria of a relatively precise technological nature. No program can proceed to development and production without a detailed description of what is to be built. But, in the words of the Assistant Secretary of the Navy:

> The whole point of the development process is to get something that we haven't got, something that we have never seen, and something that we really don't know can be produced.... We simply cannot unambiguously describe before the development begins, or at any point, in fact until we have a final object, what it is we are actually buying. (1)

There is an unavoidable element of uncertainty built into the process of translating a relatively abstract and imperfectly understood "need" into concrete specifications. The system's success in meeting these admittedly

uncertain specifications and criteria is our only measure of its operational worth short of full scale deployment; yet full scale operational deployment invariably points out that these criteria were neither complete nor entirely accurate. In many cases the validity of the target criteria is never subjected to the white heat of full operational exposure and is therefore subject to constant reinterpretation.

The uncertainty and unreliability of cost estimates have a direct bearing on risk. These estimates--which are invariably inaccurate in the early stages of the acquisition process and even more pronounced where the desired technological advance is greatest--go into the DOD planning machinery and tend to be "cast in concrete." Congress and the aerospace contractors learn of them and use them for their planning purposes. Despite changes made to the program elements in the interest of improving the technology, adjusting to the threat, etc., the early cost estimates themselves are seldom revised. Faulty estimates in the planning stages ultimately either require relief from the specified cost, schedule and performance constraints or they result in cost growths.

Technical Uncertainty

Description.--Target and technical uncertainties are very closely related. To distinguish between them, one must separate the uncertainty of the criteria used in solving a technical problem from the technical solution itself. Technical uncertainty treats the question of whether a system can be developed at all, within any time frame and for any cost, or the degree of difficulty which will be involved in building it.

Discussion.--The entire concept of state-of-the-art is a highly subjective one. There is considerable difference of opinion among technologists as to

what is meant by the statement that something is "technically feasible" or "within the state-of-the-art." Our main purpose in this section is not to become engaged in a semantic argument over the meaning of these terms, but to point out some practical considerations arising from the concept of "state-of-the-art." Before an analyst can predict the difference between what is available and what is considered advanced technology, he must decide on some definition of the term. In those production processes which are routine and repetitive in nature there is understood to be a body of general knowledge immediately available. Access to this knowledge is easily achieved. Development, on the other hand, is concerned with one-of-a-kind projects such as complex weapon systems. The state-of-the-art in such advanced development and manufacturing processes may be widely dispersed, may involve proprietary information and will usually vary greatly between contractors and government laboratories. It is in these latter kinds of undertakings that the degree of technological readiness requiring special expertise is uncertain.

For the last several decades the developments in U.S. weapons systems have reflected an engineering "doctrine of quality" which stressed advanced technology at the expense of quantity. (2, p. 1; 3, p. 64) The business and political environments encouraged this doctrine and magnified the problem of making necessary tradeoffs. This has led to a situation of technological myopia which has downgraded any efforts to develop a management perspective aimed at (1) correctly assessing what is required and can be achieved within dollar and time constraints, (2) formulating technical predictions in a way that will permit verification and (3) budgeting resources to accomplish the technological objectives. The assessments of the past have been extremely error-ridden, useless and difficult to refute. They were useless and irrefutable because in stating that a certain performance was physically

possible, they often ignored the important time and cost constraints. Many cost overruns begin with optimistic estimates of the state-of-the-art.

When does the solution to a technical problem lie beyond the program constraints? When is a problem beyond the present capabilities of the scientist and engineer? The difference between these two questions is real and lies to a large extent at the basis of technical uncertainty. In those situations where unanticipated problems arise--problems which obviously cannot be forecast in advance with a high level of confidence--the technical difficulties which they pose may not be accurately assessed. If these problems occur at a time when hardware is being built and tested, the design engineer may not wish to consider the problem as being insoluble for fear that his peers and supervisors might downgrade his engineering ingenuity. The Program Managers in both government and industry often react to technical uncertainty by designing around it, by making tradeoffs and finally through submission of Engineering Change Proposals. This may help to explain why many of the engineers and managers interviewed in the preparation of this report stated that it may not be possible to tell if a technical problem is genuinely insoluble. The human factor which motivates man to attempt the impossible--and in some instances succeed--also causes him to conceal, put-off, or uselessly persevere over a genuine "insoluble." Even here, it is really a question of time and resources. Who is to say that given enough time and money the problems could still not be solved?

This complex interaction of engineering ingenuity and the "state-of-the-art" forms the basis for many problems in the weapons acquisition process. The inability to accurately assess the technical feasibility of large-scale technological endeavors within stated cost and time constraints results in changes to an already "slippery" technical baseline. Thus, purely

"technical" problems contribute to the overall uncertainties of development.

Internal Program Uncertainty

Description.--Internal program uncertainty involves those uncertainties that originate within the program as a result of the way in which it is organized, planned and managed. The boundary between internal program and progress is largely an organizational one; internal program uncertainties are those that are under the jurisdiction of the Program Manager. Internal program uncertainty is the uncertainty inherent in selecting a particular method or managerial strategy for dealing with a given problem, not the inherent uncertainty of the problem itself.

Discussion.--Internal program uncertainty enters the weapons system acquisition process in a variety of ways. These generally occur chronologically as follows:

- o Uncertainty of initial estimates in all other areas--process, technical and target--inasmuch as they impact internal program styling, planning and management.
- o Uncertainty in selecting among various acquisition strategies.
- o Uncertainty in program management.
- o Uncertainty of program outcome.

The first three areas of uncertainty listed here are closely intercoupled, not only with each other but with process uncertainty as well. Perhaps the most difficult aspect of analyzing process and internal program uncertainty is in deciding where to assign the role of uncertainty in estimates of the available resources.

One of the earliest "hard" program decisions is the selection of an acquisition strategy. Uncertainty concerning which acquisition strategy to use--total package procurement, full prototyping, competitive

development of selected components, competitive paper studies, etc.--is amplified by the uncertainty in early estimates of the resources needed and resources available, considerations which we will discuss in our treatment of process uncertainties.

Having selected a particular acquisition strategy, program styling must be established. The object of selecting suitable program styling is to strike the proper balance among the basic program elements of cost, schedule and performance. The balance struck among these by internal program styling should reflect an accurate assessment of process and technological uncertainties. It should be emphasized that this is not a static balance, but a dynamic one which changes constantly throughout the life of the program.

Today's turbulent environment requires that flexibility be built into every weapon system program. Efforts on the part of the government and industry to definitize the system prematurely or a failure to make adequate contingency provisions virtually guarantee program imbalances. Flexibility in planning and management is a necessary prerequisite to government and industry effectiveness.

Finally we must consider the uncertainties in desired program outcome. The Program Manager is faced with a large number of competing--and often equally valid--requirements which he must reconcile through the mechanism of program management. Congress is primarily concerned with the program's immediate fiscal impact. Planning staffs at the Service level will be concerned with the "ilities"--reliability, vulnerability, maintainability, etc.--and with projected impact on force structure. The using organization will be intensely interested in performance and operating costs. The military Program Manager and his industry counterpart must, in one

way or another, reduce the uncertainties generated by tension among these competing requirements if program success is to be insured. They must also have the authority--or, as a minimum, the influence--to do so.

Process Uncertainty

Description.--Process uncertainty is fundamentally different in nature from target, technical, and internal program uncertainty. Process uncertainty originates outside the program but directly affects the program's "critical mass" of support. The Program Manager can do little to alter process factors. His only reliable tactic for minimizing the impact of process uncertainty is to style his program in conformity with the realities of the external process environment, and to be sensitive to changes in that environment. The uncertainties here are much broader in scope than in any of the other categories and concern Service priorities, other weapons programs, roles and missions debates, DOD policy, the President's budget and congressional political considerations.

Discussion.--Discussions of process uncertainty should consider the following subjects:

a) Uncertainty that resources which are required will be available when needed to support the program.

b) Uncertainty surrounding the criteria to be used in the initiation and approval of program changes.

Resource availability centers mostly around political considerations. How much money will Congress be willing to obligate for the program in question? How do the resource requirements mesh with established fiscal and budgetary planning? How much control and surveillance over the program will Congress exercise? What will be the relative priority among the Services for the monies allocated by Congress? This last question

points out one of the single greatest process uncertainties in a program. Where the likelihood of a shortage of funds is high, managers must be provided some basis with which to style their programs so as to reduce the impact of stretchouts, etc. and to develop contingency plans. In today's environment there is great uncertainty about "which" programs have "what" priorities.

The uncertainties associated with the criteria to be employed in program approval, contractor selection and in the review and evaluation of on-going efforts focus on the functions and activities of the Defense Systems Acquisition Review Council (DSARC). Associated with this organization and these processes there is an adversary role to be played at different levels of management. The DSARC must examine in detail and be critical of those program's being promoted and advocated by the Services. The DSARC has been organized to complement the Development Concept Paper system and to advise top DOD management of the status and readiness of a major program to proceed to the next phase in its life cycle. When events and parameters in these programs exceed previously agreed threshold limits, the program must be reviewed to determine if it should be permitted to go forward as presently configured. Working in this capacity, the Council must consider important issues which are "non advocate" in nature. The absence of a data base, comparable in size and quality to that of the program advocates, and the absence of a staff of professionals to analyze the data and those courses of action resulting from it, seriously impair the effectiveness of the DSARC's non-advocate role. Considerable uncertainty is thereby attached to whether or not the thresholds established for each program are realistic standards of measurement for deciding when a program should progress to

its next major milestone, and whether or not the threshold has, in fact, been attained. Uncertainty surrounding the DSARC's decision process is typical of process uncertainty.

The boundary between process and internal program uncertainty is somewhat arbitrary because they are both intimately concerned with resource allocation. An example of this can be seen in the projected funding requirements for a typical system.

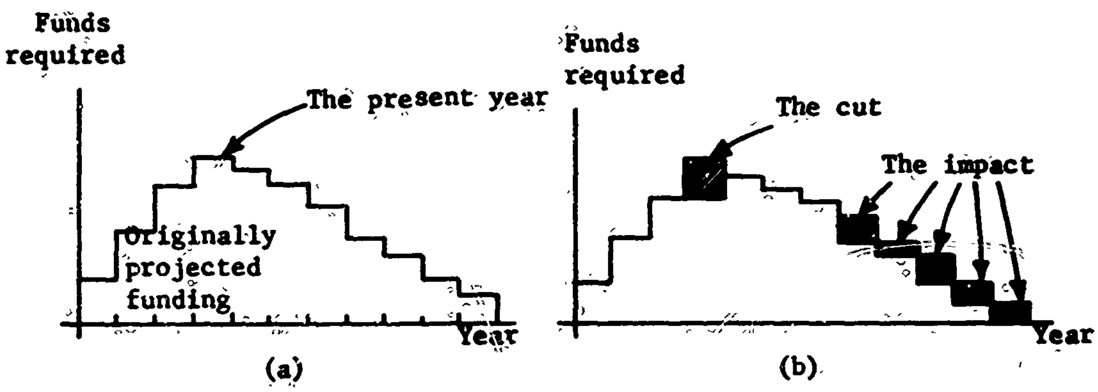

Figure 2.
Funding for a Typical System

Figure 2a shows the original projected fiscal requirements which must be met if program schedule and performance goals are to be achieved. Firgure 2b shows the possible downstream impact of this year's cut in funding. Whether the funding cut would, in fact, occur was a process uncertainty. The way in which it will impact downstream is in part a process uncertainty and in part an internal program uncertainty. Note that the total program expenditure is expected to increase. This is partly due to inflation, a process factor. The total program cost also

increases because of loss of program efficiency and contract overhead--program factors.

Summary

The weapons Acquisition Process is a tremendously complex, turbulent network of activities. Although there is no satisfactory static model of this process, there are a great many organizational and co[illegible] [illegible]s that assist in its description. The breakdown of the system life cycle into the phases of Concept Formulation, Validation, Full-Scale Development and Production is one of these techniques. Since the overall acquisition process is characterized by high uncertainty, any conceptualization that clarifies the uncertainty present in it should be welcomed. It is toward this goal that the categories of TARGET, TECHNICAL, INTERNAL PROGRAM and PROCESS were developed. The boundaries between categories are not always clear and distinct, but the power of the concepts merits examination in more detail. The next chapter will examine how to resolve the uncertainties or to manage around them.

CHAPTER III: RISK MANAGEMENT

The preceding chapter introduced the four categories of uncertainty which this study group believes encompass the prime uncertainty present in a weapon system development program. The statements concerning the source of said uncertainties are illuminating, and indeed useful, in that many of the sources may be abated by remedial actions of the DOD--and by the Service Secretaries and their Civil Service and Military Staff subordinates. But such changes do not occur overnight, and may never occur at all due to other constraints extant in the government. The problem then remains--how to resolve the uncertainties into known quantities or to manage around them if this cannot be done. It is this problem we now address.

Our objective in this chapter is to introduce some techniques available to the developer in his task of generating alternative courses of action to be used in bringing his weapon system development program to fruition. In conducting a risk analysis, one is required to generate an initial set of alternatives, assess the risk in these, modify them to reduce the risk, reassess them, and continue this process until one alternative may be chosen as the optimum end. Both the initial generation and the subsequent modifications may be accomplished by using the techniques presented here--and others since this is by no means an exhaustive list.

The generation of alternative strategies for the acquisition of a particular weapon system is a highly innovative process, and the individual generating such procedures can only depend upon his experience (which in some cases is seriously lacking), case histories of similar programs, and his and his associates' imaginations. There is a dearth of information

in the management literature in the field of strategy generation. The major focus is in the field of analysis.

> Assuming known goals and clear planning premises, the first step of decision making is the development of alternatives. It is rare for alternatives to be lacking for any course of action; indeed, perhaps a sound adage for the manager is that, if there seems to be only one way of doing a thing, that way is probably wrong. What the manager has probably not done is force himself to consider other ways, to open his eyes and develop alternatives; unless he does so, he cannot know if his decision is the best possible. (8, p. 152)

The Comptroller General's Office has recommended in a report to the Congress (5) that a "decision-guide" identifying the various alternative acquisition strategies should be created--one which identifies the features, characteristics, and shortcomings of each. Such a guide, to possibly include contracting strategies and procedures, would be immeasurably useful to anyone initiating, modifying, or managing a weapons system acquisition--and especially useful to the novice Program Manager (as many of the military PM's are). Our efforts here constitute an attempt to start such a guide.

The intent is for the developer to ascertain, based on the definitions introduced in the previous chapter, which uncertainties are paramount in the program under consideration--and to generate alternative strategies for development using the techniques most effective against those uncertainties. The developer may then proceed to conduct risk analyses (as specified in Chapter V) on these alternative strategies, change them as indicated by the analyses, and select the optimal one based on his utility considerations.

"The fact that one does not need to make decisions in the face of major uncertainty but can instead take steps to reduce uncertainty is

an essential quality of the development process." (7)

Management Under Target Uncertainty

Target uncertainty can be a significant factor in a development program. It has been frequently pointed out that a weapons system rarely, if ever, is used for the original purpose for which it was conceived. Very frequently the planned target does not fully characterize the real need that exists. As a development program proceeds, important design requirements are recognized by both the developer and the user which were not previously considered by either.

Techniques which are effective for reducing risk arising from other forms of uncertainty are not necessarily appropriate strategies for use when target uncertainty is a key factor. For example, a parallel development technique for a system or subsystem, which is valid under technical uncertainty, is not highly effective when target uncertainty prevails (see the section of this chapter entitled "Parallel Development" for a discussion of this concept). Unfortunately, those actions which test and clarify critical assumptions in the specifications may not be carried out until very late in the development cycle. Thus parallel development may have to be carried very far along before sufficient data have been gathered to identify an appropriate choice. This may result in very expensive development costs.

Under performance target uncertainty, outcomes tend to be much more desirable when the following actions are taken:

1. During development of the weapon systems, continuing effort is expended, in refining the threat which the system is being acquired to counter. This in turn should allow a finer specification of the performance parameters required and consequent resolution of the

target uncertainty (the requirements staffs of the military services are charged with keeping the developer, whether he be military Program Manager or his predecessor, appraised of the trend in performance requirements). The further downstream in time a system development program gets, the more costly and calamitous are the effect of changing the required performance.

2. A single, promising approach is carried forward through the development cycle to the point where it can be tested in operational or operational-like conditions before a final commitment is made for production.* Once preliminary studies have been accomplished, a course of action should be selected which concentrates as much on clarifying the appropriate target requirements as it does on identifying and solving the technical problems.

With these concepts regarding the management of target uncertainty in mind, the following actions are proposed as potentially useful for minimizing or reducing the risk associated with target uncertainty.

1. The criteria for development should be stated in such a way (as, for example, in terms of upper and lower limits on performance requirements) that tradeoffs can be continuously made between technical design and operational requirements throughout the system development.

2. A Steering Group should be established combining representatives of the development management team and the user to review design and operational requirement tradeoffs. Such a group should be constituted at a sufficiently high managerial level as to minimize the time required to effect desirable changes (see section entitled "Uncertainty of the Process for Change Approval" later in this chapter.

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*See the section of this chapter, "Operational Prototyping."

3. Since considerable time has usually elapsed between the approval of stated requirements and award of the development contract, it would be appropriate to establish a 30-60 day "cooling-off" period between source selection and the contract award. In this non-competitive environment, the development and operational segments of the Service and the Program Manager should review the stated requirements with the contractor and update them if necessary. At the time the development contract is awarded, the winning contractor has supposedly established his capability to deliver a system to meet the main features of the stated operational requirements. Small changes in the requirements should therefore not invalidate the selection of that contractor for the program. A proposal such as this will probably not decrease the optimism acknowledged by industry as being a major part of the replies to RFP's, but should certainly tend to diminish the number and magnitude of Engineering Change Proposals submitted subsequent to contract award.

4. Uncertainty concerning the estimates of time and cost required to develop a weapon system have been identified as target uncertainties. Most people involved with weapon system acquistion realize that these estimates are just that, but they are treated by some others as deterministic quantities. Their probabilistic nature should be acknowledged by quoting "risk profiles" (as in Figure 1, Chapter II) for weapon system acquisition courses of action*--and if a single number is required for budgeting or other such purposes, the risk associated with that cost or time should be included. The "region of uncertainty" in the risk profile may be decreased by increasing the accuracy of cost and schedule

*Chapters IV and V discuss in much greater detail the means to obtain these profiles--and their uses.

estimates (for subsystem developments) input to the risk assessment which produces the profiles. Toward this end, estimating techniques must be improved and seminars or courses created to instruct those charged with the estimating activity.

Management Under Technical Uncertainty

The technical uncertainty prevalent in a development program may be assessed as high or low by answering the question: Do I know how to build it--that is, do I know how to construct and mate the parts and establish quantity production procedures to turn out large numbers of the item, if that is required? If the answer is yes then the technical uncertainty is low, and conversely. High technical uncertainty is best resolved by high order hardware proofing activities like model testing and the three types of prototyping. Varying degrees of technical uncertainty require different levels of proofing or uncertainty resolution. Glennan (7) has provided a classification of proofing techniques which ranges from paper analyses, in the case of low technical uncertainty, to prototyping, where technical uncertainty is predominant. Glennan's levels are: (1) paper analyses, (2) design review by experts, (3) focused applied research, (4) model testing, and (5) prototyping. They are all described here for organizational simplicity.

If very high technical uncertainty exists, parallel development is indicated. (That concept is described immediately following the discussion of proofing techniques.)

Proofing Techniques

1. Paper Analyses. This technique is characterized by extensive use of mathematical models of the physical world representing the

environment within which the system must operate and a mathematical abstraction of the system itself. A wide variety of hypothetical designs can be investigated, and at least preliminary judgments can be made on the suitability of alternative designs and development strategies. Analyses and paper studies are most useful in programs that lead to highly specialized products--where there is little or no interaction between component parts so that they are sufficiently independent of each other to allow disjoint treatment. One of the major approximations required in the use of mathematical models involves simplification of the interrelationships between components, wherein a great deal of realism is sometimes lost--especially in complicated programs.

2. Design Review by Specialists. If a development strategy or set of alternative strategies is proposed, a design review team of experts in varied specialties can be used to assess the degree of uncertainty present in their particular areas of expertise. This is again a device which avoids the expense of actually building prototypes and is a concept which has been extensively employed during the 60's. A proposed method of attack, when critiqued by experts in fields such as powerplants, materials, structures, performance, human engineering, and reliability may be modified to conform to what is known based on the experience of the expert reviewers. This procedures is iterative, must start off with a "straw man," is highly susceptible to human frailties such as optimism and cynicism, and will not necessarily produce an optimal course of action. The parochial interests of each "-ility" expert, and the personality differences between them can lead to unbalanced programs. There is, in addition, the uncertainty as to whether

all the necessary "-ility" experts have been included in the review process. There is on record the case of an anti-mortar radar developed for the Army, which met all design criteria and operated perfectly--until deployed operationally in Korea. It turned out that the radar's operating frequency exactly duplicated the mating call of a moth found locally in great abundance, and the antenna was completely blocked out by enormous swarms of romantically inclined insects. No entomologists were included on the design review team.

3. Focused Applied Research. The first type of uncertainty resolution involving actual hardware construction is called "focused applied research." Once a basic design has been selected for development there will be many questions surrounding the materials, manufacturing techniques, or other technical inputs which may be resolved by controlled laboratory tests. These tests share with analysis the quality of abstraction. The test of the strength of a piece of material is usually conducted with a standard test sample of material. The shape is determined by the testing procedures and the strength will be measured according to some standard method. However, in actual usage the material will be shaped differently, subjected to different stress levels and dynamics, and will no doubt have peculiarities of fabrication. The ability of a designer to translate the test results into valid information concerning the actual design will determine the usefulness of the tests. Such focused applied research results should be more cautiously applied when the product differs greatly from previous ones.

4. Model Testing. The next category for resolving technical uncertainty involves model testing. It differs from focused applied research in that a model represents a partial synthesis of components,

and it differs from prototype testing (discussion follows) in that it seriously abstracts from the final product.

The use of a model in development follows from a recognition that the complexities of a design prohibit complete analysis, perhaps because of the complex interaction of components or because the second order effects are important. These models must be tested in a simulated environment and because of this, a calibration of the environment is required. To the degree that the environment is known and understood, the calibration is relatively straightforward. We are reasonably confident, for instance, of test work in subsonic wind tunnels because of the wide range of past experience with the translation of wind tunnel results to actual practice. These tunnels and experiments are generally "well calibrated." When we seek to extend our results beyond our experience, however, the problems of calibration increase and our confidence in the tunnel results should decrease. Serious problems can be expected in interpreting the results when significantly different (advanced) products are being developed.

5. Prototyping. The most expensive but most realistic category of uncertainty resolution involves the use of prototypes in testing programs. The word "prototype" has many connotations, particularly in connection with military developments, but for present purposes a prototype will be a full sized or nearly full sized model that can be tested in the true physical environment in which the final product will be used. Because it represents a first approximation of a product and is expected to be changed as a result of testing, it will generally (except possibly in the case of "production" prototypes) be built with a minimum of specialized capital equipment so as to save both money and time.

Moreover, a prototype can be a subsystem, a collection of subsystems, or a complete system depending upon the needs of the development project.

Prototypes do overcome some of the disadvantages of lower-order proofing techniques. Since prototypes are usually full size, results obtained in tests do not have to be scaled. And since they operate in the environments in which the final products will be used, there are no calibration problems.

The DOD Project Hindsight Study indicated that, in many weapon system development programs, approximately one-third of the new scientific and technological information needed to satisfy system/program requirements was generated after contract initiation. One of the most powerful tools to demonstrate that this information is well in hand is that of prototyping. Normally a prototype of one sort or another will coincide with a development milestone--express or implied.

Peck and Scherer (13) indicated that use of prototype testing and multiple approaches tended to decrease the time required to gain program fulfillment--for a specific performance vector. These were, however, programs which included a high degree of technological uncertainty, which probably would not have been resolved satisfactorily by paper studies or sequential attempts to develop quantum technology jumps which are the complements of prototyping and parallel approaches. The time compression, however, is not free--in that program funds need be allocated against the efforts. They proposed a functional relationship as follows based on studies of major weapons systems acquisition programs where technical uncertainty was considerable:

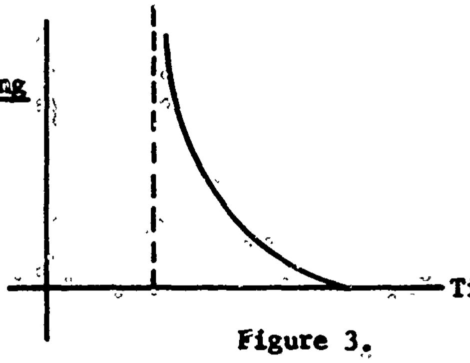

Figure 3.

Functional Reltionship of Prototyping Funds to Project Development Time (For a particular performance vector)

The rationale for the curve's shape being: (1) for the asymptotic nature at a minimum time--there is, in any program, a serial sequence of operations which must be performed regardless of whether one prototypes of not, and (2) for the intercept on the abscissa--no prototyping means no funds devoted to that activity, but less extensive hardware proofing studies, which are the alternative, do not always yield valid results due to the approximations and errors made therein--resulting in rework and restudy to discover the faulty components when the program end item is finally delivered. (3) The convexity toward the origin was an empirically observed phenomenon.

There are three basic prototyping philosophies, dependent upon the relative time that the prototype is constructed and the reason for which it is required. They are development prototyping (brassboarding, breadboarding), production prototyping, and operational prototyping.

a. Development Prototyping (brass- or breadboarding)

The objective for the use of prototypes in development is

basically to provide engineering data complementary to that provided by analysis, design review, and focused applied research. Development prototypes are normally constructed and tested during the engineering development phase of a system (e.g.: the AWACS radar set) and can vary from a breadboard of a subsystem to a complete flying prototype.

> The usefulness of the development prototype is greatest if it can be built and tested with only a fraction of the engineering effort (and time) required for the production prototype. The objective should be ~~to select the fundamental or key~~ technical problems that are not subject with assurance to analysis alone, and to design and build equipment that will provide the necessary engineering data. Formal engineering of the type necessary for a production release can often be avoided, and features should be omitted if they are not essential to meeting the purpose of the development prototype. The determination of the objectives and resulting characteristics of this type of prototype requires keen engineering judgment if it is to be most useful. Careful review is necessary to ensure that it is built to meet a genuine need that cannot be satisfied with less expensive means, and that the prototype does not "grow" with the addition of costly features unnecessary to its fundamental purpose. (4)

b. Production Prototyping

The objective for the use of production prototypes prior to production commitments is to provide information on producibility. Here the prototypes are constructed near the end of the development program, looking as close as possible like the first production article. Not only is the prototype itself evaluated but so are the tools which created it. In production these tools are the production processes, procedures and organization that will ultimately produce the system. Here the major issues are producibility and production costs.

> A major purpose of building and testing a production prototype is to establish with assurance that the engineering design is qualified for a production release.

> The engineering drawings and specifications controlling the manufacture should in general be formal and thorough, and should represent as accurately as possible the concept of the equipment that is to be deployed. The technical effort that is required for such a formal release is substantial and involves considerable time and cost. (4)

c. Operational Prototyping

The objective for the use of operational prototypes is to establish the feasibility of military utilization in the fields of performance, maintainability, safety, etc. Paper studies in these areas are only tentative and advisory, suggesting whether operational prototyping is necessary. This prototype concept is effective against target uncertainties and demonstrated capabilities may be assessed as sufficient or not when the prototype is tested. The Hawker-Siddely P-1127 (Harrier) VTOL close support aircraft now being tested by the U.S. Marines under combat conditions constitutes such an operational prototype. The Marines are attempting to establish whether or not a sufficiently improved close-support capability justifies buying the aircraft in numbers.

Parallel Development

Where a quantum jump in technology is required, parallel development by different organizations of duplicate research and engineering toward a common goal, whether it be paper analyses or hardware, is a technique to be considered. The rationale is that two or more groups trying to achieve a goal in different ways will lead to a more desirable product than if only one group were to attack the problem in its own way.* The number of parallel developers can be decreased as

*Abernathy indicates that the marginal gain in learning decreases with an increase in the number of parallel developers, however.

estimates improve and the required technology is seen to be more attainable. In the atomic-bomb project, one of the most spectacularly successful military projects the United States has ever undertaken, the parallel-path strategy was employed. James Conant wrote in a letter to Bush on May 14, 1942:

> All five methods will be entering very expensive pilot plant development during the next six months. ...(But) while all five methods now appear to be about equally promising, clearly the time to production ... by the five routes will certainly not be the same but might vary by six months or a year because of unforeseen delays. Therefore, if one discards one or two or three of these methods now, one may be betting on the slower horse unconsciously. (12)

If the early stage development costs are small and the expected decrease in technical uncertainty large, it pays to run parallel projects. And if the competing projects are similar in their estimated cost and performance because there is little data on which to base estimates, but they are quite different in design, then it certainly pays to run several projects in parallel. The parallel-path strategy is rational when time is important. When time is not pressing, the uncertainties which call for the parallel-path strategy if development is attempted now might better be interpreted as a signal that development should not be attempted until more background research has been done.

An additional wrinkle has been added to the parallel development concept in the suggestion to pursue "Parallel Undocumented Development"--which was very favorably received by the GAO. (5,10) There is little new in the concept and it merely realizes that the less paper work required from a contractor, the more resources he is able to devote to the development problem at hand. A quote in Mr. Nash's article is worthy of note, however:

...in terms of total system cost, parallel development may not be excessively burdensome. George Schairer of the Boeing Company has estimated that parallel development through the prototype phase adds 6 percent to the total cost of an aircraft program with a contemplated production of 500 planes.*

Other Considerations

Technical uncertainty is often increased by the source selection process through apparent technical transfusion prior to source selection. This apparent transfer of knowledge gives rise to the conclusion that any of the several contractors can build the proposed weapon at the current state-of-the-art. However, we conclude that whatever actual technical transfusion exists at this point tends to be superficial and is not sufficient to make all proposals really technically equal because the technical capability of these contractors is not the same. The result is to transfer the emphasis in source selection away from technical uncertainty issues onto lowest cost bids. We suggest that the DOD reinforce current policies to prohibit the government from assisting in technical transfusion before the source selection decision. This may, for example, preclude competitive negotiation.

Technical uncertainty in some programs could be reduced if all possible subcontractors were made available to the winning prime contractor. Subcontractors are normally "locked up" by the prime contractors during competition. This precludes some prime contractors from being capable of state-of-the-art performance in some areas. We should institute procedures whereby the government has complete choice of subcontractors to work with

*The Role of Competition in Aeronautics, The Wilbur and Orville Wright Memorial Lecture of the Royal Aeronautical Society, Dec 5, 1968; quoted by R. C. Nash (10)

the winning prime contractor. Such choice should include the option to reject a subcontractor who may have "teamed-up" with the selected prime during competition, as well as to select the best subcontractor to replace the one dismissed. One method of doing this, of course, involves identifying those subs whose products are desired by associate contracts and providing the subcontractors' products to the prime as GFE.

Unanticipated Technical Problems

One of the biggest problems inherent in programs with a high degree of technical uncertainty is the inability of the developer to specify <u>all</u> the uncertain component development problems. They are frequently encountered during development, or after production (e.g., TFX swing wing pivot), and have been termed "unknown unknowns" by the AIA in its studies since they cannot be foreseen when development is started. As they appear during the development cycle, they frequently cause performance degradation, schedule slippages, and cost overruns. The only way they can be handled is to identify them as they occur, and then to resolve them in accordance with such techniques as hardware proofing and parallel development. A risk analysis as proposed in this report <u>cannot</u> identify "unk unks." Funding of some sort is required to pay for the resolution of such technical "unk unks" once they are surfaced, but timely discovery is of paramount importance. A good cost, schedule, and performance parameter tracking system will indicate the symptoms of surfacing "unk unks," and it remains for the program developer to identify the precise cause.

A reporting system which indicates the current estimates of <u>final</u> cost, schedule and performance and the <u>current</u> status of the same items is necessary to inform the PM of the progress and status of his systems,

and to aid in the identification of "unk unks." If progress is not preceeding as scheduled the indication is that some previously unforeseen problem area is rearing its head and identification procedures should be initiated. Spending, or even budgeting, in excess of that scheduled; excessive time spent on activities in comparison to that scheduled; and comparatively slow progress in approaching required performance parameters are danger signals which will be sounded by tracking the current system status.

Regardless of the parameters reported, the system used to do the reporting to the PM should be the same as that used within the contractor's own management information system. Rather complete latitude is provided for information systems to be used for project control by the current DODD 5000.1 (1 Jul [illegible]), DODI 7000.2, and other applicable directives; and as long as the PM is getting the information he requires, there is no need for duplicate information systems, reformatted reports, or the like. The contractor's own system which he has designed and understands, and more important--uses himself, is the best one.

Many displays have been generated to allow management to monitor the progress of programs under their control, but most suffer from the same deficiency--they are confined to two dimensions. They can display work completed against time, or funds spent against time; but little correlation between these two highly dependent variables has been shown. One of the major weapons systems now under development uses the cost, schedule, and performance data provided by the contractor in response to DODI 7000.2 to display cost and schedule as a function of time in the following manner:

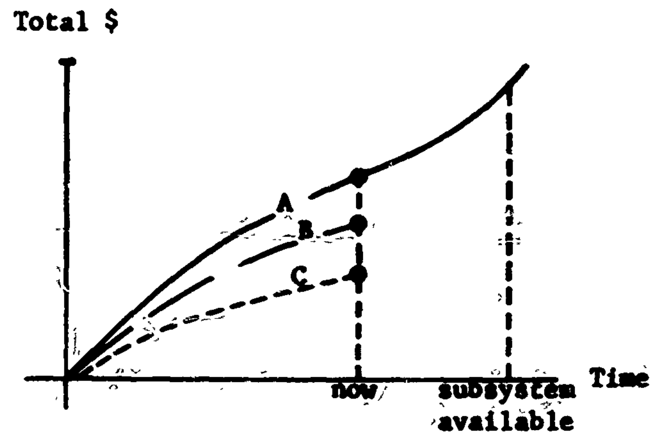

Figure 4.

Cost/Schedule/Performance Parameter Tracking Graph

a. Abscissa - time initiation of development of the subsystem being tracked. Here a subsystem is used in the sense of a specific set of work packages as specified by the work breakdown structure.

b. Ordinate - cumulative dollars.

c. Curve A - cumulative budgeted cost of scheduled work packages included in this tier level item. This is of necessity a monotonically non-decreasing curve and terminates at the end item availability date.

d. Curve B - the actual cost of work performed on this subsystem - which represents money either paid or committed to the contractor due to completion of work packages (the work packages are assumed to be satisfactorily completed; that is, the performance specifications are met.)

e. Curve C - the "earned value" in this subsystem item - the budget value of completed work packages in the subsystem.

The B and C curves consist of connected points reported on a frequent (monthly) basis. The relative vertical orientation of the latest points leads to the analyses presented in the rows of matrix below:

A: Budget Cost for Work Scheduled (BCWS)

B: Actual Cost of Work Performed (ACWP)

C: Budgeted Cost of Work Performed (BCWP); "earned value"

condition \ relative vertical curve orientation	A B C	A C B	B A C	C A B	B C A	C B A
Cost Overrun	X		X		X	
Cost Saving		X		X		X
Possible Sched. Slip	X	X	X			
Possible Sched. Adv				X	X	X

Table 2

Matrix Analysis of the Cost/Schedule/Performance Tracking Graph

The situation depicted on the graph actually existed in a current weapon subsystem development. With just curves A and B represented, it would appear that funds were not being spent as fast as budgeted--but the addition of Curve C indicates that the planned number of work packages have also not been completed. The actual situation is not optimistic but is definitely a cost overrun and possibly a schedule slippage in

addition. The possibly is due to the fact that work packages might have actually been completed which were not, a priori, scheduled to be done at this time--and others, which were budgeted to be done, could have been deferred. If these latter are completed later on at a lower cost than anticipated, the schedule slippage might not be real.

The approximate amount of time involved in schedule slippage (or advance) may be obtained by converting the dollar difference between curves A and C to time by dividing the dollars by the current rate of contractor earning (dollars per time).

This is but one example of a cost/schedule/performance tracking (controlling) system that allows revelation of anomalies appearing in the program.

Management Under Internal Program Uncertainty

Obviously, flexibility is the key in combating the problems arising from internal program uncertainty. If the developer is unsure that the development course of action that he has selected is indeed the appropriate one to counter the problems in his program, he must maintain the capability to change the emphasis of his strategy. If his "unk unk" discovery process reveals a large technical uncertainty rearing its head, he must be prepared to shift strategies and adopt some high order of hardware proofing, maybe even parallel development. Such a course was necessary in the case of the 60-foot armored launched bridge developed by the Army. They already had a 40-foot version and proposed to build upon it by changing the material used in constructing the bridge carried by the tracked vehicle from steel to aluminum--the centers of gravity and total weights were to remain essentially the same. This was thought to be a

rather low technology uncertainty program until someone questioned the ability of the contractor to weld aluminum in the sizes and shapes specified--it had never been done except on small parts under laboratory conditions. Immediately the program assumed high technical uncertainty and a development prototype consisting of welded aluminum members was scheduled. Additionally, a fallback position calling for riveted connections was planned. As it turned out, the aluminum welding on the prototype went well, the uncertainty in the program was reduced through the knowledge gained, and the fallback position was unnecessary. Both the institution of a component prototyping strategy during development, and the scheduling of the fallback position were examples of the flexibility required in the program.

To counter the uncertainty in program planning, separate (parallel) analyses or design reviews by specialists are possible useful techniques under program uncertainty--especially when conducted early in the development process. The insights gained by examining different proposed coureses of action for system development will indicate whether there is a great deal of program uncertainty due to program styling and planning. If more than one expert organization indicates a similar strategy, then program uncertainty due to the uncertainty of the approach method is reduced. The converse is true if widely variant approaches are suggested. When there is uncertainty concerning the methods, management, or costs associated with actually building the production article, production prototyping might be indicated. This process is extremely expensive however, and should be clearly justified in each case.

The central figure in the weapon system acquisition process is the Program Manager. It has been suggested that most of the ills of the acquisition process could be cured by selecting better Program Managers. While this recommendation would help the situation, we find the PM's responsibility greatly exceeds his authority. He is responsible for his program, but he is quite often the victim of an ill-defined target, inadequate resources, and a changing process. In short, many of his problems are caused by factors well beyond his control. One way to reduce these problems is to foster a better understanding of the weapons acquisition process and better communication between top decision makers and Program Managers. The OSD should conduct a symposium for the managers of major DOD programs where ideas, strategies and management techniques could be exchanged. Each Service Secretary might consider having a similar symposium for his service. The purpose of such meetings would be to more closely integrate weapons development with national objectives and to facilitate the exchange of successful program management techniques.

Not all the services are in favor of establishing permanent career fields for Program Managers. If a service feels that line officers should be "rotated through" a program office rather than remain in the development field, it behooves that service to establish effective program office organizations. Unfortunately, organizations then tend to drive the PM-- and those which are in existence for long periods of time stagnate due to lack of dynamic leadership. Program management is too important a function to not be a career field in each service.

Continuity in the assignments of good Program Managers from the "selling" of the program through the delivery of the operational systems to the services will have a pronounced effect on the reduction of program

risk. The DOD should further enhance the role of the Program Manager and other key personnel in the development career field. Reassignments of key personnel should be made only after major program milestones have been satisfied. We agree strongly with the Blue Ribbon Panel (15) recommendation to increase the authority and career opportunities of the Program Manager and personnel. These key personnel should be identified for tours of duty of sufficient length to assure program continuity. It may be appropriate, for instance, to assign key personnel to the program through the next major milestone with options for longer tenure. Whenever possible, these key personnel should overlap assignments with their replacements, so that a maximum of continuity is maintained.

A clear system of rewards and penalties must be established that provides for rapid impact on the Program Manager's career. Diligence and, above all, honesty must be rapidly rewarded; inefficiency, poor judgment and dishonesty must be corrected equally as rapidly. But more than honesty is the issue. Program Managers are in a crucial position of authority. They must impose an orderliness of their own design on the program so that the process (system) does not drive them. PM's that let the system drive them will soon find themselves driven into cost overruns, schedule slippages and performance degradations. Such lack of management ability is clearly not acceptable. One of the best ways to make a change in the Program Manager's career is to give him visibility. High-level visibility should be provided to the managers of all high priority programs. For instance, periodic briefings of high-level Service officials, such as a, Service Secretary, should be made a part of every high priority program. If intermediate level briefings are desired they should be scheduled back-to-back with the high-level

briefing to minimize the Program Manager's separation from his direct management function.

Management Under Process Uncertainty

For the purpose of discussing useful management techniques when process uncertainty is anticipated to be significant, the general area of process uncertainty has been divided into the following subgrouping:

- o Uncertainty of the criteria for program approval
- o Uncertainty of the process for change approval
- o Uncertainty of scheduled resources

1. Uncertainty of the Criteria for Program Approval. Many of the uncertainties of the process surround the program approval process. Exactly what it takes to get through the DSARC and move into the next phase of the acquisition cycle is unknown. For example, current policy directs that one of the criteria for passage must be a completed "risk analysis," yet what goes into such a document or what would constitute a "good" one is as yet unspecified in an official way. A part of this uncertainty is caused by the DSARC itself. The DSARC is not a body dedicated to a single purpose. Rather, it is an extra duty for individuals, each of whom spends most of his time running a large defense staff in OSD. In the absence of a DSARC staff, there is no way to generate a real "feeling" for the DSARC's criteria for approval without approaching one of the high level appointees. Thus when OSD says there must be a risk analysis on each program before it is allowed to pass the DSARC, there is no staff to follow-up and provide guidance to the Program Managers on the preparation of such a document. The assignment to DSARC of a small staff (perhaps from within DDR&E or Systems Analysis) might reduce the large amount of uncertainty surrounding the approval criteria.

The DSARC might well become a part of the Office of the Deputy Secretary of Defense.

2. Uncertainty of the Process for Change Approval. The Program Manager is the central figure in the Weapon Acquisition Process; he stands in the center, among the forces of Congress, OSD, his Service Headquarters Staff, his parent Development Command, and the using Command. The rhetoric of defense management says that he is the individual who makes tradeoffs among cost, schedule, and performance. But the reality of the matter is that he has severe constraints, imposed by each of the above mentioned organizations. Except for relatively minor decisions, it is unlikely that the Program Manager will ever make a significant tradeoff by himself. Indeed, the image of a modern Program Manager is often one of a traveling salesman, flying from his office to the contractor, to various headquarters, or searching the Pentagon for men who can give him authority to make changes in his program.

This problem, as it faces the Program Manager, is one of divided authority and diffused responsibility. The basis for having a multitude of staffs and a diffuse network of command is that many parts of the various organizations need information on the new system. Yet this need is seldom balanced by a benefit in meaningful terms. One alternative that is only now being explored is limiting the number of individuals that can have a major voice in the development of a major program. At present there is no clear-cut appeal level for tradeoffs between the authority granted the military PM and the DSARC level. Perhaps it is time to explore the possibility of a Service Steering Group for each major program. This group would be composed of representatives from the major organizations involved in the approval process for

program changes. It could consist of delegates from the Headquarters Staff, the Developing Command and the using Command. The function of the Group would be to evaluate and approve tradeoffs in the program on a timely basis. The managerial level of the Steering Group could be tailored to the priority and size of the development program, being perhaps general officers for major programs and lower ranking officers for others. However, it would be essential that the representatives be delegated the authority to make tradeoff decisions for their organizations--not just coordinate the proposals. The absence of decision-making authority would mean the group would become merely another of the many obstacles in the path of the Program Manager. The scope of the Steering Group's authority would necessarily have to be limited to making tradeoffs within the thresholds established by the DSARC. Tradeoffs beyond the DSARC thresholds would require another trip up the DCP/DSARC path.

3. Uncertainty of the Scheduled Resources. The magnitude of this problem can scarely be underrated. The point is simply that the number of agencies that can tamper with the scheduled resources (primarily funding) of an individual program is so large that budget uncertainty is almost always the single largest process uncertainty. Basically, every organization above the Program Manager reserves the right to cut the program funds. The potential impact of this uncertainty can be illustrated by an example. The B-1 program is one of the Air Force's highest (if not the highest) priorities. Yet there is a great deal of uncertainty about its getting scheduled funding from Congress. The impact, in terms of total system cost growth, of receiving a significant cut in one or two year's funding is potentially greater than the impact, in terms of cost savings, of making a major change in the operational requirements (such

as from supersonic to subsonic). The required stretch out of the program necessitating parts of the development to be deferred to later times would increase costs by reduced development optimization and by inflation.

An effective technique to try to counter drastic unexpected budget cuts might be the establishment of a sensitivity analysis with frequent updating which would provide more realistic and timely information on the overall cost impact of changes in scheduled resources when cutbacks are proposed. Such information might have a deterring effect on the approval of resource decrements when the consequences are made clear. This would mean that studies on the effect of reduced resources would have to be frequently performed, not just when the need dictated. Generally, sufficient time has not been available in the past, when such information has been requested, to conduct an accurate analysis.

CHAPTER IV: RISK ASSESSMENT

General Considerations

Risk has previously been described as a measure of a particular aspect or characteristic of a proposed weapon system program. Specifically, risk is defined as the probability of not being able to acquire a weapon system of specified performance characteristics within an allotted time, under a given cost and by following a specific course of action. A formal risk analysis is an explicit investigation of the factors which affect the risk associated with a program and a written presentation of this and other relevant information to the decision maker. A risk assessment is a comprehensive and carefully structured approach for estimating the risk associated with a particular alternative. Risk assessments are then a part of risk analysis.

Risk assessment is not a new notion. To a lesser or greater degree, the problems of cost growth, schedule slippage, and performance degradation have been addressed previously. The process, however, was largely intuitive, incomplete, and informal. It was intuitive in that a structured quantitative approach often gave way to intuition and "blackboard analysis." It was incomplete in that detailed analyses of isolated aspects of the problem were rarely brought together and integrated in a broader analysis. And it was informal in that the results of the assessment were often not written and explicitly incorporated into the review/approval/control process.

The greatest potential value of a formal risk analysis is at the very early stages of the concept formulation phase when the range of possible alternatives is greatest and the really substantial decisions

have yet to be made. Unfortunately, because of a lack of both quality and quantity of input data, it is precisely at this point that a risk assessment is most difficult to perform and the output most suspect. This basic dilemma, though less acute in lower risk situations, will always exist. However, significant improvements over current practices are possible immediately. All of this is not to suggest that a risk analysis at the early stages of the concept formulation phase is of little or no value. Major decisions will be made at this point, and they will be made with or without a risk assessment. But decisions made without the benefit of such an assessment will be made in the absence of potentially valuable information available from no other source.

Risk changes with time, and may even increase with time. Therefore, although an early initial risk assessment is necessary, it is by no means sufficient. A risk assessment should be performed at each of the major decision points in the development of the program, each new assessment using the previous assessment as a jumping-off point and improving and updating it to reflect changes. Thus, a risk assessment should be performed at discrete points in the development process, but the updating of inputs to reflect changes is accomplished continually. These points are worth stressing. Risk assessments are useful only if they can affect a decision to be made among various alternatives. Needless to say, the assessments must also be a quality product.

A risk assessment of good quality requires the co-ordinated efforts of a highly qualified, interdisciplinary group. This group should consist of trained analysts in mathematics, probability, statistics, operations research, and computers who are capable of putting the assessment together, cost analysts to provide cost estimates, design and

engineering people to provide technical performance information, and production people to provide schedule and integration information. Additionally, experts in the various technical disciplines must be available for the group's use. These experts supply much of the basic input data necessary for the assessment, while the function of the risk assessment group is to aggregate these inputs, extract meaningful information from them, and provide this information to the decision maker in an understandable form.

What has been termed a risk assessment here may sound to many like a good systems analysis approach to the problem of risk. And so it is. Unfortunately, once that connection is established there is a strong tendency on the part of many to transfer all the grievances associated with poorly done systems analyses to risk assessment and, if their aversion to systems analysis is great enough, to dismiss it entirely.

This attitude is unjustified, though understandable, for several reasons. Aside from the fact that some poor quality work has been done in the name of systems analysis, there are two main factors which contribute to this situation. One is that the decision maker frequently does not understand the analyst or what he does, cannot effectively communicate with him, and is unable to evaluate his product. On the other hand, the systems analyst often tends to suffer from a lack of perspective and fails to appreciate the fact that, as important as it is, his output is only one of the inputs which the decision maker must act upon. Additionally, there is a very strong inclination on the part of the analyst to re-define a problem which he is given to one which he knows how to solve by techniques he is familiar with.

These considerations suggest the need for still another member of

the risk assessment group. Namely, an individual who can act as a liaison between the decision maker and the risk assessment group--one who can understand both sides and effectively communicate between them. Unless there is such a built-in provision for reducing the misunderstandings, distrust, and antagonism which could build up between management and the assessment group, its usefulness to the decision maker is questionable. The assessment group and the decision maker must work in concert if the output of the group is not to become yet another required but ignored paper study.

As has been previously stressed, the results of risk assessment are of value only if they can affect a decision. But a risk assessment is just part of a risk analysis, and a risk analysis is just one of the many inputs which should be available to a decision maker. It is not a panacea, and it should definitely not become a master cult claiming ability to solve all the problems in the weapon system acquisition process. On the other hand the contribution of a good risk assessment in this area can be both unique and substantial.

Even in those situations where the quality of the risk assessment is restricted by scarce or poor input data, such as at the early stages of the concept formulation phase, the structured investigation and inquiry which precede the actual assessment can be of great value in calling attention to potential problem areas. As more resources are devoted to the assessment and more data becomes available to work upon, the better will be the results of the assessment.

The results are not without cost, however, and the level of effort has to be commensurate with the value of the program. A massive risk assessment on either a relatively minor program or on one which does

not represent a state-of-the-art advance is unwarranted. On the other hand, against the background of staggering cost overruns of most major weapons systems, a good risk assessment which can help reduce these excessive costs will pay for itself many times over.

Quantitative Disciplines Involved

In this section, a very brief treatment of certain of the more significant disciplines involved in quantitative risk assessment is given. It should be noted that each of the areas mentioned has an extensive literature (a part of which is referenced in the Bibliography) which is impossible to summarize in just a few pages. Nevertheless, an attempt will be made to give the reader a nodding acquaintance with each subject and to highlight the advantages and limitations in its use.

Subjective Probability

In the development of a weapon system (or indeed any new product) it is impossible at the outset to know with certainty what the final outcome will be in terms of completion time, cost, and performance. At the same time, decision makers and technical experts are not completely ignorant of what the outcomes may be. Their state of knowledge is somewhere between these two extremes, and it is useful to have a language which will express their <u>degree of belief</u> that certain outcomes will occur. Subjective probability is such a language.

By convention, a subjective probability of 1.0 is assigned to an event which the assessor is sure will happen and a probability of 0.0 is assigned to an event which he is sure will not happen. For events whose occurrence is uncertain in the mind of the assessor, a number between 0.0 and 1.0 is assigned, which reflects his degree of belief

that the event will happen. The only additional restriction on the assignment of subjective probabilities is that if a collection of events are mutually exclusive (not more than one can occur at the same time) and exhaustive (one of the events must occur) then the sum of the probabilities of the individual events must be 1.0.

With these conditions, "subjective probabilists" claim that the calculus of probability follows in the same way as in the more usual objective theory of probability, in which the probability of an event may be interpreted as the expected relative frequency with which it occurs in repeated experiments. While acknowledging that it is possible to express degree of belief as a number between 0.0 and 1.0, the "objective probabilist" has serious reservations about the reasonableness of any further calculation with such numbers. While this controversy doubtless will not be resolved in the foreseeable future, the fact remains that decision makers must still make decisions, and subjective probability has been shown to be a useful tool in dealing with uncertainty in a quantitative way.

Several methods have been developed for elicitng an individual's subjective probability of the occurrence of an event, and research in this area is continuing. These methods are geared to helping the individual portray in probabilistic terms what his beliefs are. They do not come to grips with the problem of to what extent his beliefs reflect reality, a limitation which should always be kept in mind.

It should also be noted that a subjective probability assigned to the occurrence of a single event cannot in any way be "validated"; so any attempt to do so is fraught with failure. The event will either occur or not occur, and will not occur with a certain probability. To

overcome this difficulty, a "theory of scoring rules" is being developed, by which the assessing capability of experts can be measured. Although this theory is in its infancy, it could be very useful in the future if the trend toward the use of subjective probability distributions for uncertain events continues.

Trend Extrapolation

Because of the long leadtimes typical in acquiring new weapons systems, it is important to have some way of estimating what level of technology may be attainable some years hence. This need is to some extent satisfied by the use of trend extrapolation, a quantitative approach for predicting future technology.

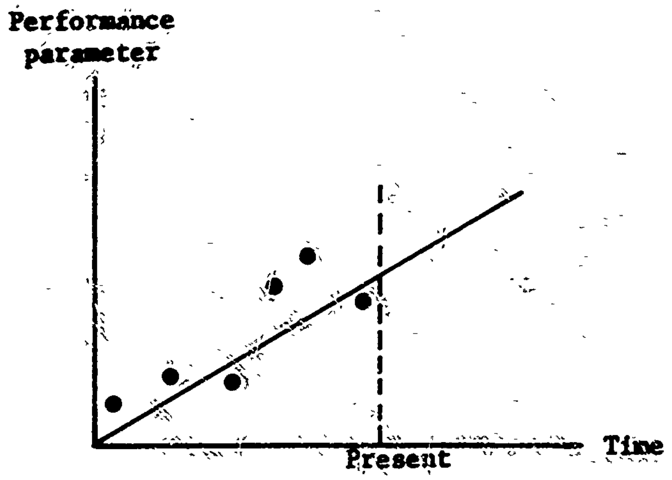

Figure 5.

Trend Extrapolation

The points on the diagram above represent specific technological achievements in the past and a curve (in this case a straight line) is fit to the points. Then, by extrapolation along the curve, one predicts

the level of performance that is reasonable to expect at some future data. In doing this, one assumes that the established trend will continue and that the present is not a point of discontinuity or a break point in the curve.

During the early conceptual stages of an advanced weapons system, trend extrapolation is a useful tool by which the planner may project the technical capabilities of his product. As the design becomes more certain it can play an important role in projecting the feasibility of subsystems and components.

It also serves to "red flag" proposals which would appear to be beyond the projected state-of-the-art. This is not to say that any projected performance parameter which lies above the curve cannot be achieved, but rather that such items should be closely watched. By the same token, projected parameters which are on or below the curve are not necessarily easily achieveable. Unfortunately, although trend extrapolation may indicate that a certain technology is reasonable to expect, it provides no information on how to go about achieving that advanced technology.

Group Assessment

Frequently in estimating cost, schedules, and performance during the development of a new weapon system, a particular question may be so complex or so important that a group of experts is asked to consider the problem, under the assumption that "many heads are better than one." Although history is replete with counter-examples, in most cases this assumption is probably valid.

The techniques of group assessment may be classified by the amount

of information each expert has about the estimates of the others.

On one extreme, each expert may be asked to estimate a given problem completely independently of the others. Then a weighted average approach is used to combine the individual answers into a single "group estimate." Although this method has the advantage of not subjecting the individuals to intimidation by others, two obvious disadvantages are the fact that the individuals cannot take advantage of the knowledge of the others and the difficulty in formulating a meaningful weighting scheme.

On the other extreme is direct face-to-face confrontation of the experts with the requirement that a group consensus be reached. Here a weighting scheme is unnecessary and full exchange of information is possible, but significant problems of intimidation may occur.

Although there are others, the DELPHI technique has been proposed as a middle ground between the above extreme alternatives. DELPHI does not permit face-to-face discussions, but rather has each expert submit anonymously the required estimate together with a written justification for it. These statements are then circulated to all the other experts and each is again asked to submit another estimate together with a justification. The process continues until little change in the estimates from round to round occurs. Then the median value is chosen as the group assessment.

In numerous experiments conducted by RAND with the DELPHI technique, it has been observed that after several rounds the estimates tend to converge on a particular value, though not necessarily on the "correct" value, of course.

Research in the area of group assessment is continuing with emphasis on methods for stripping away unwanted psychological factors and determining the optimal amount and type of information exchange among the experts.

Cost Estimating

Although there are many specialized techniques used by cost estimators, the basic method is to break the project down into subsystems and estimate the cost of each by extrapolating the cost of similar previously developed systems. This approach works reasonably well provided the subsystem to be estimated is not radically different from previous ones. When it is (and this is becoming increasingly common), the cost estimates are at best merely educated guesses.

Cost estimating methodology has already progressed far beyond the available data base. Due to non-uniform procedures and inadequate bookkeeping in the past, it is extremely difficult to ascertain the cost of existing systems. Without these data, it is hard indeed to make reliable estimates of the cost of future systems.

Another significant problem inherent in the process is the difficulty in estimating the cost of integrating the subsystems. Each integration problem appears to be quite different from previous ones, so the extrapolation technique loses some of its validity.

These difficulties are mitigated to some degree by having engineers as a part of the cost estimating team, a practice which appears to be gaining ground.

A common complaint among cost estimators in the aerospace industry is that while they usually have sufficient time to make the initial

estimate, frequently they are required to "cost out" changes to the design in unreasonably short periods of time, thereby inducing errors that would not otherwise be present.

All too frequently there appears to be insufficient communication between cost analysts and the designers, system analysts, and the management structure. More communication would undoubtedly result in timely design tradeoffs that would not impair the performance of the product, and would bring it in at reduced cost.

Finally, even though single-point estimates are required for bookkeeping purposes, cost analysts must be trained to give estimates in terms of subjective probability distributions for use as inputs to quantitative risk assessments.

Network Analysis

At the point in the development of a weapons system where the project is sufficiently well-defined that the various subtasks may be sequenced and milestones established, it is possible to use a network as a mathematical model. In this network the milestones are represented by nodes, the activities by branches, and time and cost estimates for activities by probability distributions assigned to the branches. By using any one of a number of techniques, it is then possible to obtain probability distributions for the time and cost of the entire project and the probability that it will be successfully completed. These data, then, can be easily used to obtain the risk of completion within specified time and cost constraints.

Several types of networks to represent a development project have been proposed and are in use. Probably the most widely known is PERT.

While PERT may be of value in planning a project in which there are few uncertainties, it is generally unsuitable for developing new weapon systems. The two most significant reasons for this unsuitability are the fact that the only permissible nodes are AND nodes (which means that there can be no probabilistic branching) and that critical paths are computed on the basis of their expected values (which means that paths that appear to be non-critical may in fact be the potential bottlenecks). A lesser known technique, Critical Path Method (CPM) suffers the same drawbacks.

GERT is a network technique which overcomes some of the difficulties of PERT in that it admits probabilistic branching but it suffers from a restricted number of types of nodes that may be used (in particular, AND nodes are difficult to deal with).

Network simulation appears to be the best technique available at the present time. The types of nodes and distributions on the branches which can be used are limited only by the level of the computer programming effort involved. A number of large scale simulation programs are available which would be suitable for use in a risk assessment of a development project.

Quantitative vs Qualitative Risk Assessment

The difference between a quantitative and a qualitative risk assessment is clear. A quantitative risk assessment is one in which the estimate of the risk associated with a program is expressed as a number. A qualitative risk assessment is one in which the estimate of the risk associated with a program is expressed in non-numeric terms such as high, medium, or low. With the exception of the group assessment

techniques, the disciplines which were discussed previously are all quantitative methods. Qualitative "methods," on the other hand, involve fairly simple and direct ideas such as ordinal rankings, etc.

There is no doubt that when both can be used, quantitative risk assessment is infinitely more desirable and useful. However, there are times when the numerical data which are required for a quantitative assessment cannot be obtained, and in these cases there is no choice but to employ a qualitative approach. In fact, at the very early stages of the acquisition cycle a qualitative approach may be the only one possible. The great disadvantage is that, unlike quantitative methods, it is very difficult to aggregate, combine, and compare qualitative information. However, it is a mistake to assign really arbitrary numbers simply to permit one to bring quantitative methods to bear.

Summary and Recommendation

The group assessment techniques and the disciplines of subjective probability, trend extrapolation, and cost estimating, can be used to produce terminal results or to generate inputs to the more powerful scheme of network analysis. The outputs which they produce, though useful, do not supply the kind of information necessary for a quantitative risk assessment of the type required. The technique which offers the most promise in quantitative risk assessment is a versatile, simulated network approach using group assessment techniques, subjective probability, technological forecasting, cost estimating, and others as sources of input.

Network Simulation in Risk Assessment - An Example:

It is very difficult for someone who is not familiar with network simulation to understand how it can supply information useful in a risk assessment. The following simple, but illustrative example, is furnished to provide some insight into the process and confidence in it.

Suppose a system consists of only two components, subsystem X and subsystem Y, and that the course of action to be employed in building the system is to produce each of the subsystems at the same time and then integrate them. The essential features of this simple process can be abstracted and modeled by the following network, where the nodes represent the milestones and the branches represent the activities as indicated.

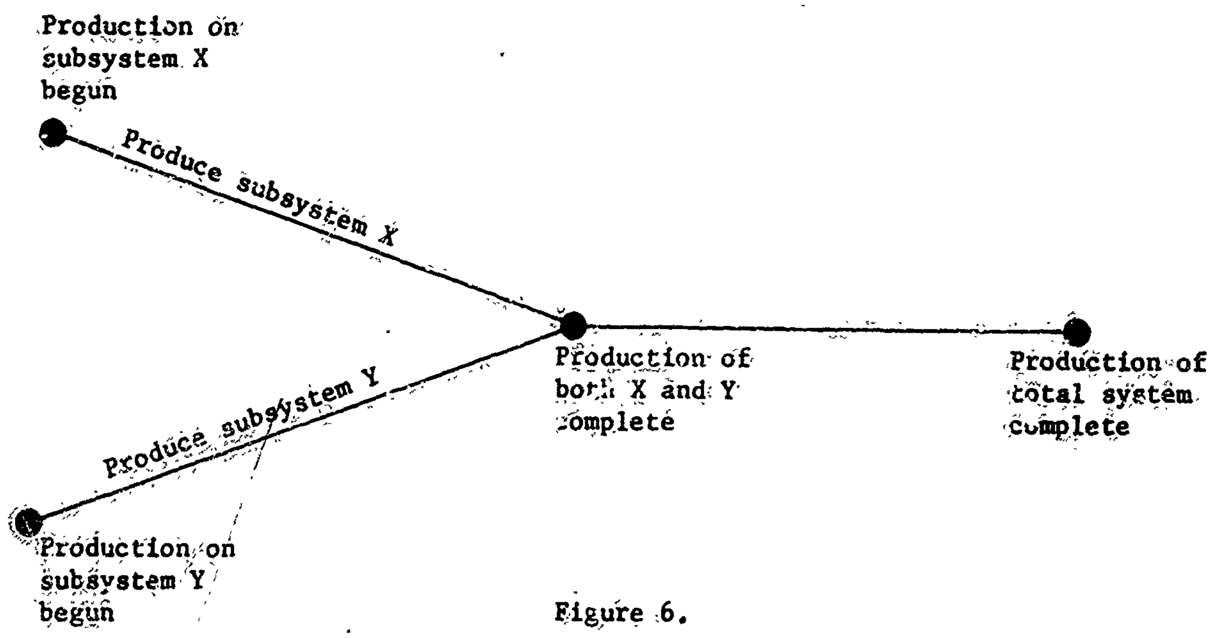

Figure 6.

Network Representation of a Simple System Acquisition

Now, although experts familiar with the technology required to produce a subsystem will typically be unable to predict precisely how long it will take or how much it will cost to build it, they will have some idea of what values are possible and which are more likely. This information is elicited from them in the form of a subjective probability distribution.

For simplicity, suppose that a probability distribution of the time, t_X , which is expected to be required to produce subsystem X is elicited from experts on subsystem X. Also, suppose that a probability distribution of the time, t_Y , which is expected to be required to produce subsystem Y is elicited from experts on subsystem Y. Finally, suppose that a probability distribution of the time, t_I , which is expected to be required to integrate the two subsystems is elicited from integration experts.

Additionally, suppose that cost estimators indicate that all costs are linear functions of the time involved. In other words, the cost, c_X , to build subsystem X is $c_X = a_1 + b_1 t_X$; the cost, c_Y , to build subsystem Y is $c_Y = a_2 + b_2 t_Y$; and the cost, c_I , to integrate the two subsystems is $c_I = a_3 + b_3 t_I$. In these equations the constants a_1 , a_2 , a_3 represent the fixed costs while the constants b_1 , b_2 , b_3 represent the time-variable costs for the prespective activities, and a specific value for each of them would be furnished by the cost estimators.

An example distribution of time and the cost equation associated with each of the three activities (branches) in the plan of action (network) employed in the building of the system are displayed in the figure below:

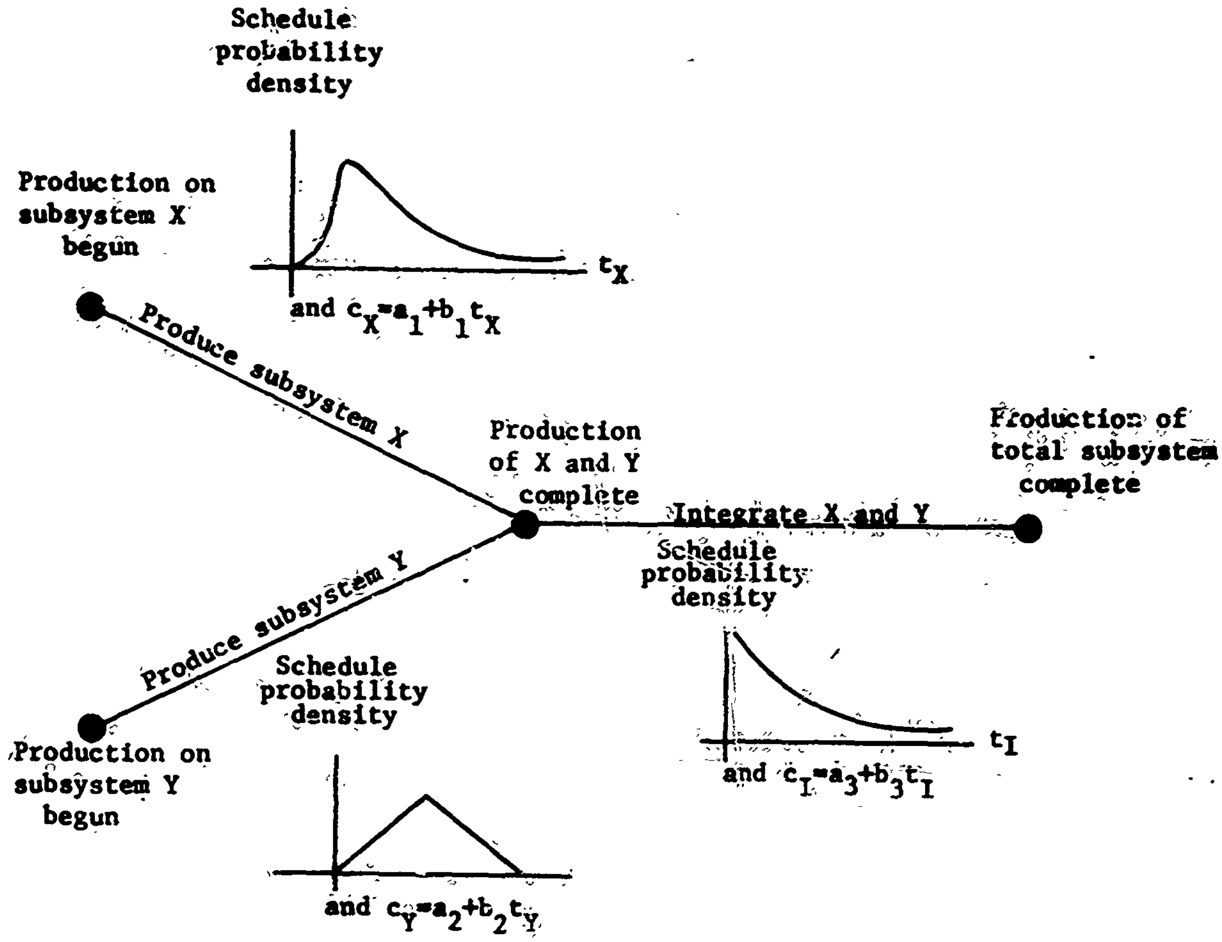

Figure 7.

Branch Parameters in the Network

The question at this point is this: Given the information above, what is the total system expected to cost and how long is it expected to take to build? The answer is provided by simulating the network, which is accomplished in the following manner.

Using a computer and random numbers, a representative production time for subsystem X is generated from the distribution of times given by the experts and the corresponding cost of building subsystem X is computed from the cost equation furnished by the cost estimators.

The same thing is done to generate a time and cost for building subsystem Y and for integrating the two.

For this first pass through the network, the cost, C_1, of building the total system is simply the sum of the three costs computed in the paragraph above. The time, T_1, required to build the total system is simply the longer of the times it took to build subsystems X and Y plus the time it took to integrate them. We have now simulated the building of the system in the computer one time and have obtained a total time, T_1, and a total cost, C_1.

Another pass is next made through the network to simulate the building of the system a second time. Since the times selected in this pass will not be the same as before, a different total time, T_2, and a different total cost, C_2, will be obtained. We now have two pairs of time and cost.

Depending on the size and complexity of the network, hundreds or thousands of additional passes through the network will then be made. This is done to give the "laws of chance" sufficient opportunity to work so that the results will be representative and in the correct proportions.

This whole network simulation process yields, among other things, pairs of total time and cost for the system. They may be displayed in a table as follows:

	Simulated Output	
Pass Number	Total Time	Total Cost
1	T_1	C_1
2	T_2	C_2
3	T_3	C_3
.	.	.
.	.	.
.	.	.
n	T_n	C_n

Table 3

Simulated Distribution of Time and Cost

where n is the total number of passes made through the network during the simulation.

The column of costs in the table above is then used as the estimate of the distribution of the total cost of the system. And from this the risk profile of cost can be constructed. Its graphical presentation might appear as follows:

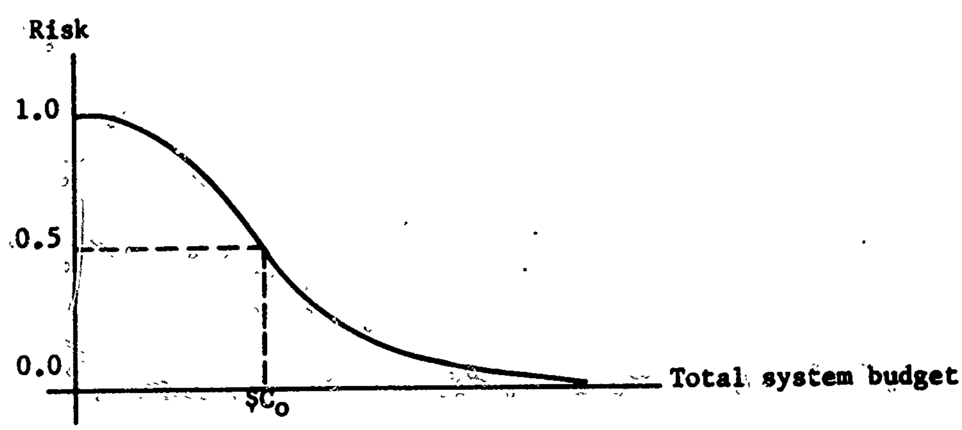

Figure 8.

Risk Profile of Cost

In the figure above, the risk associated with a budget allocation of $\$C_o$ is seen to be about 0.45. That is, the probability is about 0.45 that the total cost of building the system will be more than $\$C_o$. Where did this come from? It came from an examination of the column of simulated costs in the table above--an examination which in this case would have shown that about 45% of the n simulated costs were greater than $\$C_o$.

This same technique is used to construct the rest of the risk profile of cost, and, using the column of simulated times, to construct the risk profile of time. A similar technique can be used to construct the joint risk profile of time and cost. And increased computer programming effort and different techniques can yield yet additional valuable information on the risk of building the system.

Information of this type can now be used to make decisions concerning cost, schedule, performance, and acquisition strategies. It can be very useful in establishing realistic program budgets and schedules or in modifying existing ones. Additionally, simulations of alternate plans of action for building a system provide an excellent means of comparison among them on the basis of risk considerations.

CHAPTER V: RISK ANALYSIS

The Nature of a Formal Risk Analysis

It may seem that a natural result of a study of risk analysis would be a very detailed methodology or technical manual for actually performing a risk analysis of a proposed weapon system and a specific format for presenting the results. However, because of the great differences in various projects and the time span from the early conceptual phase to the late development phase in which risk analyses should be performed, no single style of analysis is universally applicable. Indeed, it is hard to find a single style of analysis which is even representative. On the other hand, it would be equally inappropriate for this study to be no more specific than to merely exhort planners to perform some ill-defined risk analysis.

Therefore, we have chosen a middle ground in the sense that we will identify the general nature of a risk analysis and specify the outputs that should result from a good risk analysis of virtually any type of weapon system at almost any stage in its development.

Risk analysis is a highly coordinated examination of all factors which affect the risk of acquiring a weapon system. The coordination which is necessary is between two different areas. First, there are the various strategies which are available for dealing with the problems which arise from uncertainty; i.e., the risk management strategies. These were treated in Chapter III. Secondly, there is the estimation (either quantitative or qualitative) of what the risk associated with a specific course of action actually is, i.e., risk assessment. This was treated in Chapter IV. In a normative fashion, we shall now clarify

the nature of the coordination between these two areas that is required for a risk analysis.

1. We begin at that point in time when a particular program is proposed in order to satisfy an alleged need. The first step in a risk analysis is to assess, either quantitatively or qualitatively, the risk associated with the program as it is proposed. This is accomplished by the risk assessment group using the techniques introduced in Chapter IV, and it does not rely on the generation of management alternatives.

2. The second step in a risk analysis is to identify those aspects of the proposed program which are considered to be problem areas. This is a coordinated effort between the manager and the risk assessment group. The manager, with the aid of his staff and specialists, determines those aspects of the proposed program which are potential problem areas from a technical, budgetary, production or design viewpoint. The risk assessment group determines those aspects of the proposed program which are potential problem areas from a sensitivity analysis, provided the assessment is quantitative. A sensitivity analysis is an examination of how sensitive the results of the assessment (the risk associated with the program) are to changes in the inputs. It reveals which factors, when altered, cause significant changes in the results. It also reveals which of the input factors can be altered and still not significantly affect the results of the assessment.

The manager and the risk assessment group now need to combine the results of their separate efforts and arrive at a single set of potential problem areas. Obviously, the set will contain all of those areas which both the manager and risk assessment group singled

out as being potentially problematical, and it will not contain any of those areas which both singled out as non-problem areas. However, it is not necessarily true that the set should contain all of those areas about which the manager and the risk assessment group disagree. There may be areas which the manager singles out as potential problem areas which can be shown to have little affect on the overall risk on the basis of a sensitivity analysis. These should be excluded from the final set. Similarly, there may be areas which the risk assessment group singles out as potential problem areas which the manager is confident will not change. These too should be excluded from the final set. The need and benefits of coordination in this step are clear.

3. Now that those areas whose impact on the risk of the program is potentially adverse have been isolated, the third step in a risk analysis is to propose means of avoiding or reducing these problem areas. This task falls largely to the manager and his staff and specialists and it is accomplished by the incorporation of appropriate acquisition strategies discussed in Chapter III. The result of this step is the generation of new, and presumably better, alternative courses of action.

4. At this point we are ready to repeat the above sequence beginning with step one for each of these new alternatives. This iterative process is then continued until no basically new alternatives are proposed. This, then, is the nature of a risk analysis. The formalization of the analysis is accomplished by the formating and presentation of the results to a decision maker. We now turn our attention to a normative discussion of what the outputs of the risk analysis should be.

Outputs of a Formal Risk Analysis

1. A general description of the dominant uncertainties (target, technical, internal program, or process) which directed the selection of the original course of action.

2. Identification of alternate courses of action (such as hardware proofing, parallel development, etc.) to resolve the major uncertainties.

3. A detailed discussion of the potential problems in each major program element for each course of action considered. In addition to technical uncertainties, this discussion should include process uncertainties (e.g., budget), target uncertainties (e.g., engineering specifications) and internal program uncertainties (e.g., key personnel).

4. Individual and joint risk profiles of time and cost for each alternative course of action. The inherent assumption is that the specific desired performance is obtained by following the course of action.

One of the principle outputs of the simulation of a network in which the time and cost associated with each branch is a random variable, is a joint distribution of time and cost for the entire project. And although it can be displayed in a three dimensional figure, this joint distribution is difficult to work with. However, since time and cost are dependent, it is essential to be able to see how they combine to affect the risk of the program. This can be accomplished with the aid of a joint risk profile of time and cost (which is easily obtainable from the joint distribution of time and cost) similar to that shown below.

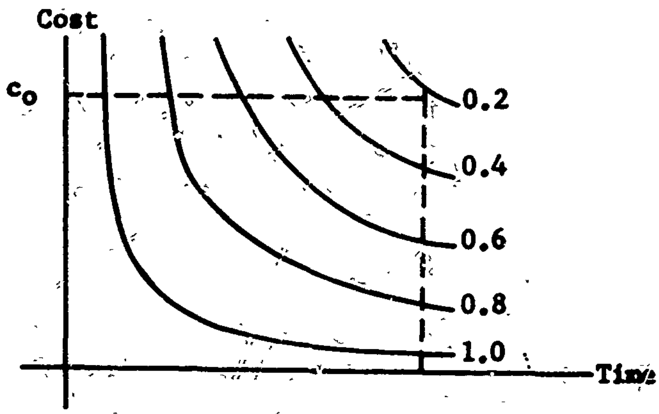

Figure 9.

Joint Risk Profile of Time and Cost

The curves on this graph are lines of equal risk. For a particular schedule and a particular budget, the total program risk can be approximated by interpolating between the curves. For example, the total program risk associated with a budget of c_o and a schedule of t_o is about 0.25; i.e., the probability that the program will cost more than c_o and take longer than t_o is about 0.25.

Also obtainable from the output of the simulation of a network in which the time and cost associated with each branch (activity) is a random variable is the individual distribution of total program cost and the individual distribution of total program time. And from these are easily obtained the individual risk profile of total program cost and the individual risk profile of total program time. Typical graphs are shown below.

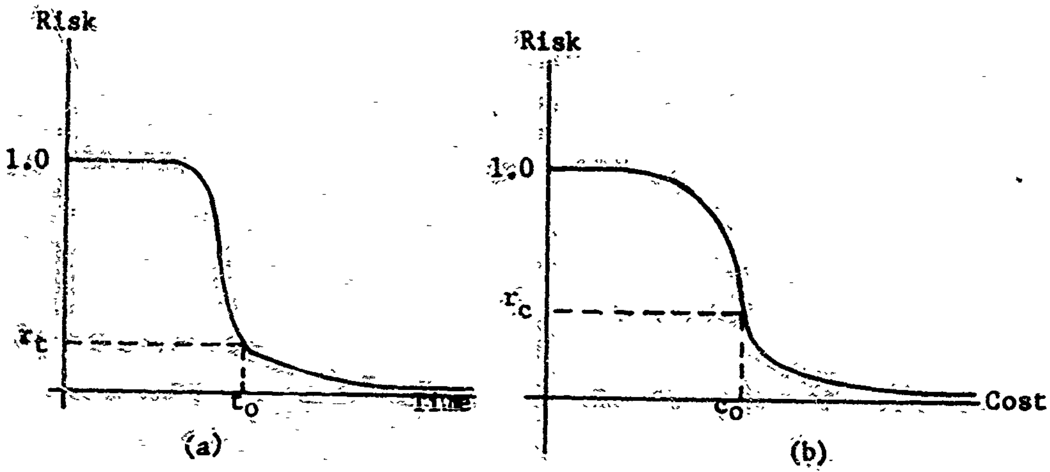

Figure 10.

Risk Profiles of Time, Cost

For example, if the total time allotted for the project is t_o weeks, then the risk associated with this schedule is r_t ; i.e., the probability that the project will take longer than t_o weeks to complete is r_t. Similarly, if c_o dollars are budgeted for the project the risk associated with this funding level is r_c ; i.e., the probability that the program will cost more than $\$c_o$ is r_c. Note that since time and cost are not independent, the probability that the program will cost more than $\$c_o$ and take longer than t_o is not $r_c r_t$ --it can only be obtained from the joint risk profile described above.

5. An analysis of how sensitive the risk profiles are to change in the inputs. It is crucial to know which factors, when altered, cause significant changes in the risk profiles. It is also essential to know which of the input factors can change and still not significantly affect the risk profiles.

6. Tradeoffs, as recommended by the Program Manager, for maintaining the overall program within specified cost, time, and performance thresholds.

7. Comparison with previous risk analyses of the same project. For example, if the risk profile of cost changed from curve A to curve B, it would indicate the risk associated with cost had increased.

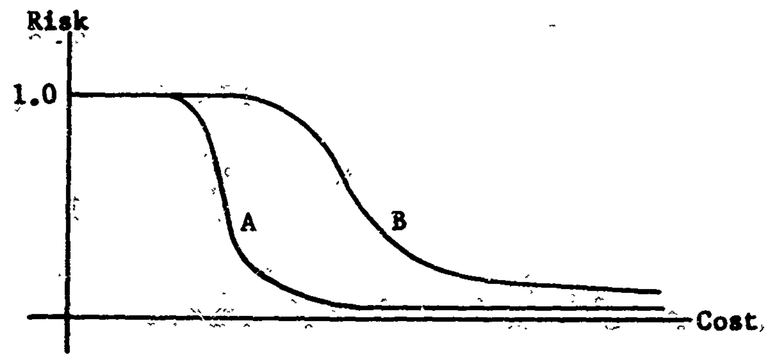

Figure 11.

Comparative Risk Profile of Cost

8. A comparison of the candidate management courses of action and a recommendation of a preferred course of action on the basis of risk considerations alone. (It should be noted that this selection is not based on considerations of national utility, political pressures, threat assessment, etc., which are other inputs to the decision-maker). For example, in the graph, curves A and B are the risk profiles of cost for two different management courses of action.

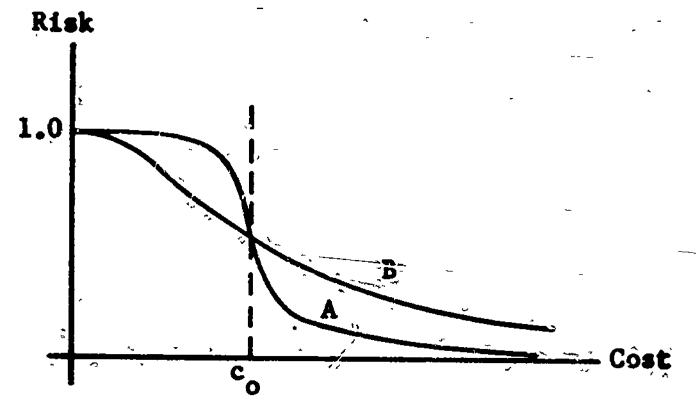

Figure 12.

Risk Profiles for Alternative Courses of Action

If c_o dollars are budgeted, the risk is the same for each; but if more than c_o dollars are budgeted, strategy A is preferred. Similarly, if less than c_o dollars are budgeted strategy B is preferred.

9. A discussion of the major assumptions and an explanation of the disparity when the results are different from those expected. This serves not only as a check on the work of the risk analysts but also enhances the credibility of the study to the decision-maker.

The Use and Benefits of a Risk Analysis

In the preceding sections of this chapter we have addressed the issues of "how to perform a risk analysis" and what the outputs of an analysis should be. We now direct our attention to a discussion of how a risk analysis should be used as an integral part of the decision-making process and the benefits which accrue from its use. A risk analysis may be part of a continuing effort by the program manager to keep abreast of his program, or it may be prepared specifically to evaluate alternatives for a major tradeoff decision by

higher level authority. Either case calls for a continuing assessment of the program risks. A continuing assessment helps to determine if there is a decision to be made, while a risk analysis helps determine which alternative to choose.

There are at least three significant uses for a risk analysis.

1. It can provide the Services and, more specifically, the Program Manager, with a capability to identify the significant sources of program risk and to evaluate each of the individual influences to determine the proper allocation of resources and efforts for the reduction and control of these risks.

The identification of major risks and uncertainties as determined by the assessment should be a part of any periodic high level review for major programs. In the past, such exposure of possible program problems has been frowned on by some Program Managers for fear that the problems would be construed to be the result of poor program management. It is time that all concerned accept the fact that, in complex weapon system development, unexpected problems will arise due to the inevitable lack of complete knowledge at program inception. Furthermore, many of these problems are outside the direct control of the Program Manager and all of them tend to intensify if left unattended. For these reasons it is essential that emerging problems be brought to the attention of a high level review as soon as they are identified.

2. Risk Analyses provide the military Services and the Office of the Secretary of Defense with necessary information bearing on the program risks in order to select an appropriate course of action, establish thresholds, or terminate the endeavor.

The Services have a vital need for a thorough risk analysis of all alternative systems considered to meet an operational requirement. In many cases it is impossible to determine today just how certain systems evolved as the answers to given threats. A meaningful and well documented analysis of the risks and uncertainties associated with each alternative system would not only assist the Service in identifying the best program to present for negotiation of the Development Concept Paper, but would tend to keep the Service in a defensible position on that program throughout the Conceptual Phase. The review of the preferred alternative by the DSARC (or Congress) at each major milestone calls for and will require a formal risk analysis. In the charter for the DSARC, authority has been granted to establish working groups to assist the Council members in their reviews. One such working group should be assembled to consider the analyses presented by the Services at the time of proposed entry of a major program into validation or into Full Scale Development. The recommendation of this group should be one of the inputs to the DSARC decision at that milestone.

3. <u>Risk Analysis provide the Program Manager with more complete information on which to base the Initial Cost Estimate (ICE) and a more meaningful method of presenting the Estimate to the DSARC and Congress.</u>

The Program Office is normally established at the time the operational requirement is defined. It is anticipated that the early risk analysis performed to select the best system during Concept Formulation would form the basis for the Program Director to develop a comprehensive list of technical uncertainties to be addressed by the contractors in competition for the development contract. Since the

Program Manager is normally responsible for preparing the cost estimate to present to the DSARC at the conclusion of the Concept Formulation Phase and for use as the Selected Acquisition Report (SAR) baseline, it behooves him to coordinate closely with the Source Selection Authority to insure that the contractors analyze and document all the major problems in developing the specified system and include the possible effects of such problems in their cost estimates. From both the Service's and the DOD's viewpoints, it is imperative that the most realistic ICE be reported in the SAR. This can be accomplished only as a result of a thorough risk analysis. No one entity affects apparent cost growth more than the Initial Cost Estimate.

During the cooling-off period between source selection and contract award, the winning contractor's risk analysis should be updated to reflect any changes that may have been made in the stated operational requirements. The Program Manager should then use that risk analysis to present, for the current required performance, a joint risk profile of time and cost to the DSARC. (Of course, the Program Manager will have already determined a desired budget and schedule from the profile.) The profile would illustrate feasible ranges of cost and schedule, and aid the Program Manager in immediate negotiation of his position, if that becomes necessary. From such a risk profile, the DSARC could also determine the program risk associated with the thresholds stated earlier in the DCP.

The primary benefits of a formal risk analysis derive from an increased degree of realism and thoroughness which this analysis injects into the program. It is the means by which the manager choses

from among the alternatives available to him in a decision-making environment characterized by over-optimism, uncertainty and change. As many members of government and industry pointed out to us during the preparation of this report, "A formal risk analysis is putting on the table those problems and fears which heretofore were recognized but intentionally hidden." What follows is a summary of the major benefits of a formal risk analysis.

1. A good risk analysis at the start of a program is one of the best ways to aid management in carrying out a careful, detailed program planning operation, and to better fix the constraints of a program (cost, schedule, performance) at the earliest phases where the payoff is greatest. Indeed, risk itself cannot be defined until the constraints themselves are clearly defined. The fixing of constraints thus becomes an iterative process which involves examining the risk of adhering to the candidate constraints.

2. By focusing proper attention on each and every program activity and event, the likelihood of adverse surprises is greatly reduced. To say the least, a good risk analysis constitutes an extremely extensive planning effort in which the aim is the identification of all expected rough spots in the entire program. Change, when it comes, is anticipated and the alternatives available for dealing with those problems which induce change are planned in advance, thus reducing undesirable impacts on program activities.

3. The careful analysis and planning operation noted above will assure a total systems approach in which engineering functions, program budgets, and time schedules are viewed together. This results

in balanced program planning, each facet of the program receiving its fair attention and evaluation, and enables program personnel to better estimate the ability of the program to reamin within the established constraints.

4. If a risk analysis is performed at the start of a program and if it is continuously updated, the problem areas will be identified as early as possible. This will permit the earliest and the most timely scheduling of appropriate efforts aimed at their solutions.

5. With maximum advance notice of the occurrence of specific problems, program management will be better able to optimize the allocation of funds to the various program activities. This enhances the likelihood of adequate apportionment of personnel and facilities geared to a realistic assignment of priorities.

6. The very process of performing a complete risk analysis forces the collection of much useful information with attention focused on critical information gaps.

7. One of the major benefits of risk analysis may be that it alerts management to the need for replacing unrealistic "single value" estimates by probability distributions.

8. As the accuracy of management and design approaches is increased through the use of probabilistic parameter descriptions, it is expected that there will be a better chance of obtaining an optimum system configuration.

9. A good analysis of risk is basic to the argument needed to justify budget requests. Officials are more likely to be convinced by sound analysis than by some rather general statement of belief--they want credibility.

10. Risk analysis provides a management tool for evaluating the decisions of the Program Manager.

Risk Analysis in the Organization Structure

The concept that a risk analysis requires an iterative interaction between the manager and the assessors, coupled with the fact that the contractor has the data, dictates that the analysis must be performed in either the military or contractor Program Office. Since the military and contractor managers for major programs are in almost daily contact, the most efficient scheme would be to have the assessment done by the contractor, with the selection of alternative courses of action made by the Military Program Manager on recommendations from the Contractor Program Manager. This arrangement keeps the military PM--the one with most to gain from a risk analysis--in constant touch with those factors affecting his program.

The picture that has been painted thus far is primarily one of program advocacy--as it should be if the Program Manager is to be expected to include such an analysis in his management techniques with any degree of utility and enthusiasm. However, if the Program Manager is faced with a decision that requires tradeoffs outside the thresholds of his charter, he should be prepared to present a complete risk analysis with several alternative courses of action and his recommendations to a high level decision board within his Service having major tradeoff authority. At the same time, PM's of major programs should be provided direct access to such a board. This board, or review council, in turn, which may vary from Service to Service, should fund an independent evaluation of the risk analysis to aid in making tradeoff

decisions. This evaluation could be done by another contractor, a non-profit organization, a consulting firm, or a Service organization, and would provide a check on the accuracy and completeness of the analysis submitted by the Program Manager's analysis. The results of the evaluation should be presented simultaneously to the Program Manager and the Council's staff and included in the subsequent tradeoff discussions. Furthermore, for major tradeoffs both the military and the contractor Program Managers should be present to interpret the content and source of the analysis.

The Service Council or DSARC risk analysis staff should be minimal in number, and serve as the administrative and advisory link between the Council and the independent evaluation group. (Note that we've used the word "evaluation," and not "analysis.") No independent group will ever be able to effectively perform a risk analysis on a program. Because they are independent they will neither have access to the vast amount of data necessary to do the assessments, nor will they be able to efficiently interact with the Program Manager to obtain the iterative selection of alternative courses of action to assess.

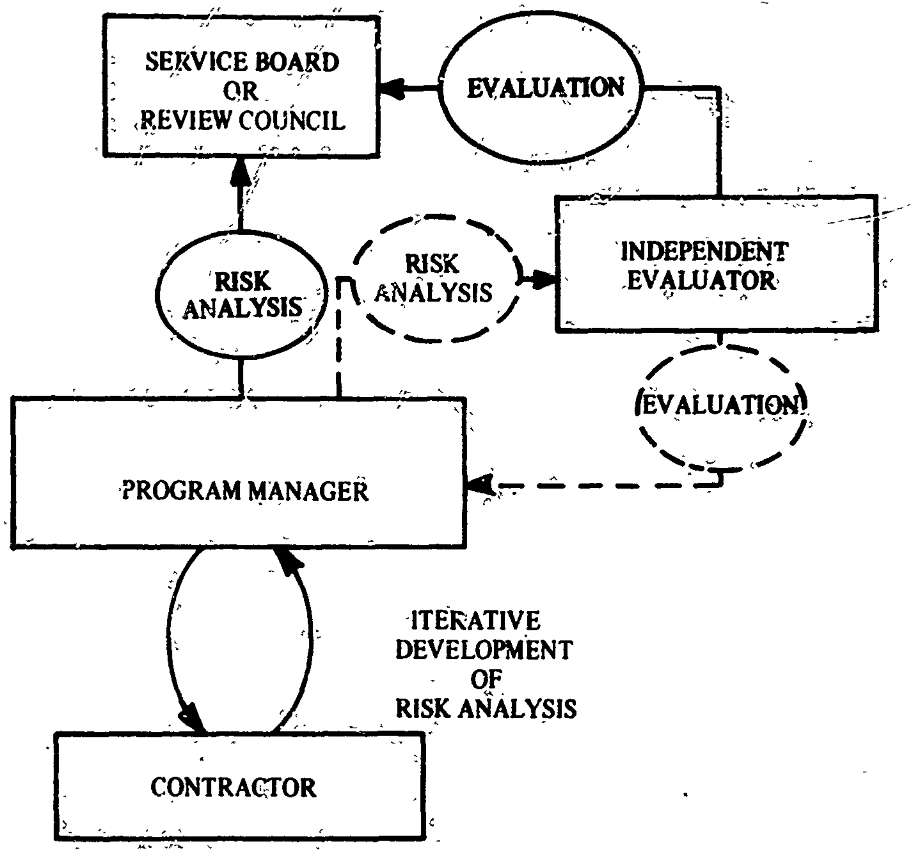

FIGURE 13.

RISK ANALYSIS ORGANIZATIONAL
STRUCTURE IN THE SERVICE

Figure 13 shows a proposed organizational structure within each Service for effectively developing and using the outputs of a risk analysis. The structure promotes utility of the analysis within the Program Office, enhances objectivity of the Program Manager in his actions outside the Program Office, and provides well formulated alternatives to those entrusted with major tradeoff authority.

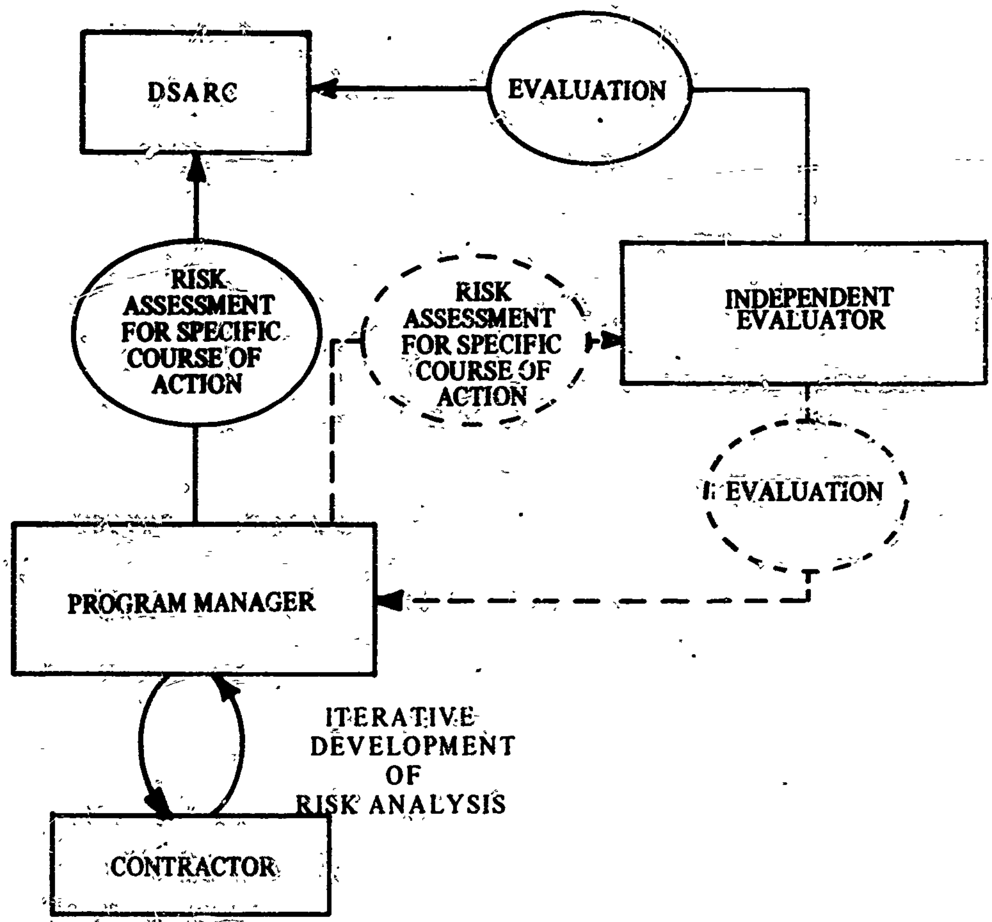

FIGURE 14.

RISK ANALYSIS ORGANIZATIONAL STRUCTURE WITHIN DOD

Figure 14 shows a proposed risk analysis organizational structure within DOD. Note that only the preferred course of action is presented to the DSARC. The innovative feature of this structure is that risk profiles of time and cost, as opposed to point estimates, are presented for review.

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

The goal of this study has been to examine the DOD Weapons Systems Acquisition Process to see if the concept of Risk Analysis can contribute. We conclude that techniques exists for conducting a risk analysis, and that such an analysis can be a valuable management tool. Guidance has been provided for its preparation and use.

The conclusions which follow have emerged as salient points of our study. Each conclusion is accompanied by a recommendation for action that we feel will help establish the role of risk assessment and analysis in the acquisition cycle. We by no means consider this an exhaustive list of proposals for change to present acquisition methods. The recommendations given here are intended to augment the suggestions given in the several other recent documents on weapon system acquisition.

CONCLUSION 1:

ONE OF THE BASIC PROBLEMS IN ANY STUDY ON RISK IS THE LACK OF A GENERALLY ACCEPTED GROUP OF DEFINITIONS. "Risk" is often used to mean the "probability of failure," but some studies include the concept of the "impact of failure" in their definition of risk. Also, many management officials have used the term "risk" in a context where "uncertainty" would be more appropriate. Thus, the general "uncertainties" of the weapons acquisition process become confused with the more specific "technical risks."

RECOMMENDATION 1:

ESTABLISH DOD DEFINITIONS OF THE BASIC TERMS AND CONCEPTS USED IN RISK ANALYSIS. A list of candidate definitions is as follows:

RISK: The probability that a planned event will not be attained within constraints (cost, schedule, performance) by following a specified course of action.

UNCERTAINTY: Incomplete knowledge.

RISK ASSESSMENT: A comprehensive and structured process for estimating the risk associated with a particular alternative course of action; also the product of such a process.

RISK MANAGEMENT: The generation of alternative courses of action for reducing risk.

RISK ANALYSIS: The process of combining the risk assessment with risk management in an iterative cycle; also the product of such a process.

CONCLUSION 2:

TECHNICAL UNCERTAINTY MAY BE ONLY A SMALL PART OF THE WEAPON SYSTEM ACQUISITION PROBLEM. SUCCESSFUL PROGRAM DIRECTION ALSO REQUIRES MANAGEMENT OF TARGET, INTERNAL PROGRAM, AND PROCESS UNCERTAINTIES.

RECOMMENDATION 2:

REQUIRE ANY "RISK ANALYSIS" TO INCLUDE CONSIDERATION OF TARGET, TECHNICAL, INTERNAL PROGRAM, AND PROCESS UNCERTAINTIES.

CONCLUSION 3:

IN THE AREA OF QUANTITATIVE RISK ASSESSMENT, AGGREGATION TECHNIQUES (SUCH AS NETWORK ANALYSIS) ARE FAR MORE ADVANCED THAN THE TECHNIQUES FOR OBTAINING INPUT DATA (SUCH AS SUBJECTIVE PROBABILITY AND TECHNOLOGICAL FORECASTING).

RECOMMENDATION 3:

FUNDING PRIORITY FOR IMPROVING METHODS FOR QUANTITATIVE RISK ASSESSMENT SHOULD BE GIVEN TO DEVELOPMENT OF INPUT TECHNIQUES.

CONCLUSION 4:

RISK ANALYSIS PRIMARILY BENEFITS THE PROGRAM MANAGER. NO AGENCY OUTSIDE THE MILITARY OR CONTRACTOR PROGRAM OFFICE CAN EFFECTIVELY PERFORM A RISK ANALYSIS OF THAT PROGRAM. Only the Military Program Office and the Contractor's Program Office have access to the vast amount of data necessary for the assessment and effective contact with the Program Manager for selection of alternative courses of action. Such a risk analysis would add a new dimension to the presentation of alternative courses of action to the level of management entrusted with major trade-off authority, particularly when supplemented by an independent evaluation of the risk analysis itself.

RECOMMENDATION 4:

o Direct each concept formulation contractor to perform a risk analysis of the system being proposed for negotiation of the Development Concept Paper.

o Direct each contractor in the source selection competition to perform a risk analysis and specifically include at least the uncertainties identified by the risk analysis performed during concept formulation.

o Require the Program Manager and the winning contractor to update the risk analysis after source selection and before contract award if adjustments are made to the stated operational requirements during that period.

o Direct the contractor for each major on-going program to conduct a continuing assessment of the risk in the program. The Program

RECOMMENDATION 4 (Contd):

Manager should use the results of the continuing assessment in his day to day management decisions.

o Require the Program Manager to present the results of a current risk analysis, to include alternative courses of action, each time the program is reviewed by higher service authority for a major tradeoff decision.

o Require the Program Manager to present the results of a risk assessment of his program, specifically the risk profiles for time and cost, each time the program is reviewed by the DSARC or Congress.

o Require an independent evaluation of the risk analysis or assessment each time the program status is presented to higher authority for a major tradeoff or milestone review.

CONCLUSION 5:

INITIAL COST AND SCHEDULE ESTIMATES FOR MAJOR PROGRAMS HAVE INVARIABLY BEEN OVER-OPTIMISTIC. THE RISK THAT COST AND SCHEDULE CONSTRAINTS WILL NOT BE MET CANNOT BE DETERMINED IF COST AND SCHEDULE ESTIMATES ARE GIVEN IN TERMS OF SINGLE POINTS RATHER THAN DISTRIBUTIONS.

RECOMMENDATION 5:

REPLACE THE POINT ESTIMATES OF COST AND SCHEDULE PRESENTLY USED WITH THE JOINT RISK PROFILE FOR COST AND SCHEDULE FROM THE RISK ANALYSIS DEVELOPED AT THE COMPLETION OF SOURCE SELECTION. At the present time, this can best be obtained from the output of a versatile, simulated network approach using inputs from group assessment techniques, subjective probability, technological forecasting, cost estimating, and others as sources.

CONCLUSION 6:

TO OUR KNOWLEDGE NO MAJOR DOD PROGRAM HAS DEVELOPED OR USED A RISK ANALYSIS OF THE MAGNITUDE ENVISIONED IN THIS REPORT.

RECOMMENDATION 6:

INITIATE TEST CASES IMMEDIATELY. FORMAL RISK ASSESSMENTS AND ANALYSES SHOULD BE USED THROUGHOUT THESE PILOT PROGRAMS TO DETERMINE THEIR FEASIBILITY AND UTILITY TO A DECISION MAKER.

For a thorough trial, prototype risk analysis programs should be initiated in programs in each of the three phases below:

- Concept Formulation
- Validation
- Full Scale Development

The characteristics of a Risk Analysis prototype should include:

- A major program or subsystem
- A relatively short duration
- Comparison with a regular program
- A formal risk assessment done by the contractor
- An evaluation of the contractor's risk analysis by an independent agency (another contractor, non-profit corporation, consulting firm, etc.)

The pilot program should assist in evaluating and determining:

- Procedures for risk assessment
- Appropriate team composition
- Input data requirements for a risk assessment
- Methods of data presentation to a decision maker
- Outputs of an acceptable Risk Analysis.
- Other problem areas.

CONCLUSION 7:

THERE IS NO "ONE BEST WAY" TO CONDUCT A RISK ANALYSIS. There are many quantitative and qualitative methodologies available to assist the analyst. The procedures to be followed for a given program should be left to the discretion of the Program Manager with the advice of the analysis team. The common denominator that should be expected is uniform output information.

RECOMMENDATION 7:

THE FOLLOWING LIST OF OUTPUTS FOR A RISK ANALYSIS IS RECOMMENDED. PILOT PROGRAMS SHOULD RECOMMEND THE MOST USEFUL OUTPUTS.

1. A general description of the types of uncertainties in the program.

2. A detailed discussion of the potential problems in each major program element (engine, etc.).

3. Identifcation of alternate management courses of action to resolve the major uncertainties.

4. Probability distributions of time and cost; risk profiles for each course of action.

5. A sensitivity analysis to determine the effect of input perturbations on the risk assessment output.

6. Tradeoff studies as directed by the Program Manager for maintaining the overall program within specified cost, time and performance thresholds.

7. Comparison with previous risk analyses to identify trends.

RECOMMENDATION 7 (Contd):

8. A comparison of the candidate courses of action and a recommendation of a preferred strategy based on risk considerations alone.

9. A discussion of the major assumptions and an explanation of the disparity when the results are different from those expected.

CONCLUSION 8:

THE CONCEPTS OF RISK ANALYSIS ARE INADEQUATELY UNDERSTOOD. AN EDUCATION PROGRAM IS NEEDED TO INSTRUCT ANALYSTS AND MANAGERS IN THE PREPARATION AND USE OF A FORMAL RISK ANALYSIS.

At the present time, there are very few people in the military services or industry who are qualified by experience to perform a quantitative risk analysis. Similarly, there are few managers who are accustomed to using the outputs of a risk analysis. For instance, probability distributions more accurately depict the risk of development than do point estimates; yet there is widespread resistance to using a probability distribution because it is an unfamiliar or perhaps suspect technique.

RECOMMENDATION 8:

FOLLOWING A MEANINGFUL PILOT PROGRAM, DESIGN AND IMPLEMENT A RISK ANALYSIS EDUCATION PROGRAM WITH THE FOLLOWING MAJOR AREAS OF EMPHASIS:

Short orientation courses in risk analysis for high-level officials who deal with uncertainties in program management and program approval.

Longer training courses to outline the details of risk assessment techniques for selected personnel who may be required to perform such assessments in the government and industry Program Offices.

Introduction of Risk Analysis as a discrete subject in the curriculum of appropriate government schools such as the Defense Weapons System Management Center.

RECOMMENDATION 8 (Contd):

Assignment of specially talented military and civil service personnel to a non-profit corporation or private consulting firm with expertise in Risk Analysis. Such selectees should already have a Master's degree in operations research, systems analysis, or some related discipline and their assignment (for up to a year) would qualify them to conduct formal Risk Analyses for the Services. This on-the-job training would significantly increase the Service capability to perform and use Risk Analyses and has its precedent in the "training with industry" program.

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